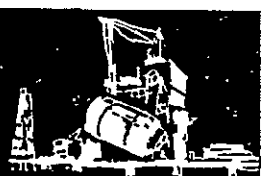
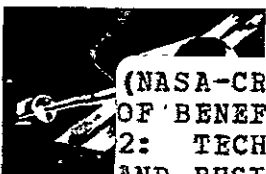
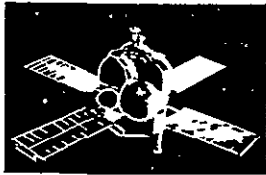
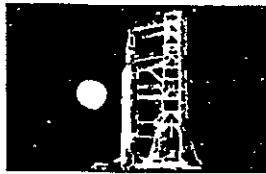
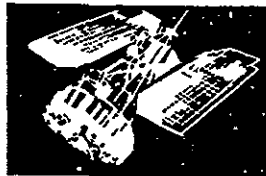


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STUDY FOR IDENTIFICATION OF BENEFICIAL USES OF SPACE

(PHASE III)

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NOVEMBER 30, 1975

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GENERAL  ELECTRIC

STUDY FOR
IDENTIFICATION OF
BENEFICAL USES OF SPACE (B.U.S.)

(PHASE III)

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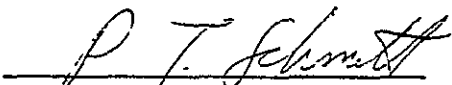
FINAL REPORT - VOLUME II

TECHNICAL REPORT

BOOK 3 - DEVELOPMENT AND BUSINESS ANALYSIS OF SPACE
PROCESSED TUNGSTEN FOR X-RAY TARGETS

November 30, 1975

Submitted Per DPD #451, DR #MA-04


P. Schmitt
Program Development Engineer


H. Bloom
Study Manager

APPROVED: 
D. W. Keller
Manager,
Advanced NASA Programs


M. A. Cramer, Jr.
General Manager
Advanced Space Programs

SPACE DIVISION

GENERAL  ELECTRIC

Valley Forge Space Center
P O Box 8555 • Philadelphia, Penna 19101

PREFACE

The Final Report on Phase III of the Study for Identification of Beneficial Uses of Space (B. U. S.) is comprised of three volumes:

Volume I	Executive Summary
Volume II	Technical Report
Volume III	Appendices

Volume II is further subdivided:

Book 1 - Development and Business Analysis of Space Processed Isoenzymes

Book 2 - Development and Business Analysis of Space Processed Transparent Oxides

Book 3 - Development and Business Analysis of Space Processed Tungsten X-ray Targets

Book 4 - Development and Business Analysis of Space Processed Surface Acoustic Wave Devices

Book 5 - Study Methods and Trade Studies

General Electric's Space Division, under contract from the NASA's Marshall Space Flight Center completed Phase I of the Study in December 1972, and Phase II in December 1973. In Phase III, the Study has progressed to the Business Analysis and Planning for the commercial development and production of the four products in Phase II:

- Surface Acoustic Wave Components
- Transparent Oxides
- High Purity Tungsten X-ray Targets
- High Specificity Isoenzymes

The methodology employed in the Phase III Study and the results of that effort are reported herein.

In addition to Key Individuals from the participating User organizations who contributed specific product, process, business and planning data in each of their respective areas,

the Study Manager acknowledges the outstanding financial and manufacturing analysis contributions of Mr. P. Schmitt, and the considerable contributions of the following: Mr. U. Alvarado and Mr. M. Clarke of the Study Team in analyzing and organizing the wealth of data accumulated; Mr. K. Taylor, the MSFC Contracting Officers Representative (C.O.R.) for the study, in providing key technical suggestions and direction to the overall effort as well as establishing space processing payload guidelines, Mr. G. Wouch, Dr. E. Okress, and Dr. B. Noval of General Electric's Space Sciences Laboratory, in providing supporting space processing data, and Mr. B. Klawans and Mr. F. Curran of General Electric's Systems Operation and Computations Component in programming and processing "INVEST", the interactive profitability analysis program.

As noted in the Final Reports of earlier Phases, publication of this Phase III report neither implies NASA endorsement of any specific product, process or venture identified during this phase of the Study, nor a NASA commitment to pursue any program defined as part of this Study.

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SECTION I

INTRODUCTION

This volume comprises preliminary development plans, analysis of required R&D and production resources, the costs of such resources, and finally, the potential profitability of a commercial space processing opportunity for containerless melting and resolidification of tungsten. The aim is to obtain a form of tungsten which, when fabricated into targets for X-ray tubes, provide, at least, a 50% increase in service life. The work reported herein is a continuation of investigations into the space processing of which have been conducted in Phases I and II of NASA Study Contract NAS8-28179 (1971-1973).

Technical support for these investigations has been provided by General Electric Medical Systems Division's X-Ray Systems Department, Milwaukee, Wisconsin, primarily by

Mr. R. Hueschen

Mr. B. Goode

Mr. W. D. Love, and

Mr. G. Wouch of GE Space Sciences Laboratory

2.

The baselines selected for development planning are conceptual, and were established to provide a means of assessing overall technical and economic feasibility under conditions of limited experimental and space processing information and very long range market, space facility, and cost projections. These baselines can be expected to change, perhaps even drastically, as later analytical and experimental investigations continue.

I.1 BACKGROUND

While there are a number of applications of Tungsten, or its alloys, in which strength at high temperatures as well as very low ductile-to-brittle transition temperature (DBTT) are needed, the primary application of interest, in terms of quantities required and economic or social benefit, is that of fabricating x-ray targets.

Figure I-1 pictures a typical medical X-ray tube. In this configuration, for each exposure, the electron beam imposes a severe thermal shock on the target, which is being rotated to "spread" the thermal load. To meet customer-required power levels in X-ray equipment presently requires the use of targets made of a Tungsten/10% Rhenium frustrum applied to a molybdenum substrate. Such targets are guaranteed to deliver 20,000 exposures at 150 KVP, 250 ma, and 1.25 second exposures taken at the rate of 2 exposures per minute on a 2 mm focal spot. Failures due to the thermal shock and/or centrifugal force occur as targets rupture, or fissure, which decrease x-ray generation. It is anticipated that targets fabricated from fine-grained space-processed Tungsten would deliver 50% more exposures and with less x-radiation fall-off after that number of exposures.

Since completion of the Phase I Beneficial Uses of Space Study⁽¹⁾, in 1973 a Tungsten of low DBBT for this and other applications has been under experimental study by General Electric via levitation melting. It is anticipated that a specimen of high purity Tungsten heated to, and above, melt temperature away from container walls, and allowed to supercool, will solidify so rapidly that its grains will not have sufficient time to grow to large size. The resulting Tungsten boule, formed of many, small grains, is

(1) Study for Identification of Beneficial Uses of Space (Phase I), NAS8-28179, Final Report, GE Document #73SD4259, December 10, 1972 and April 23, 1973.

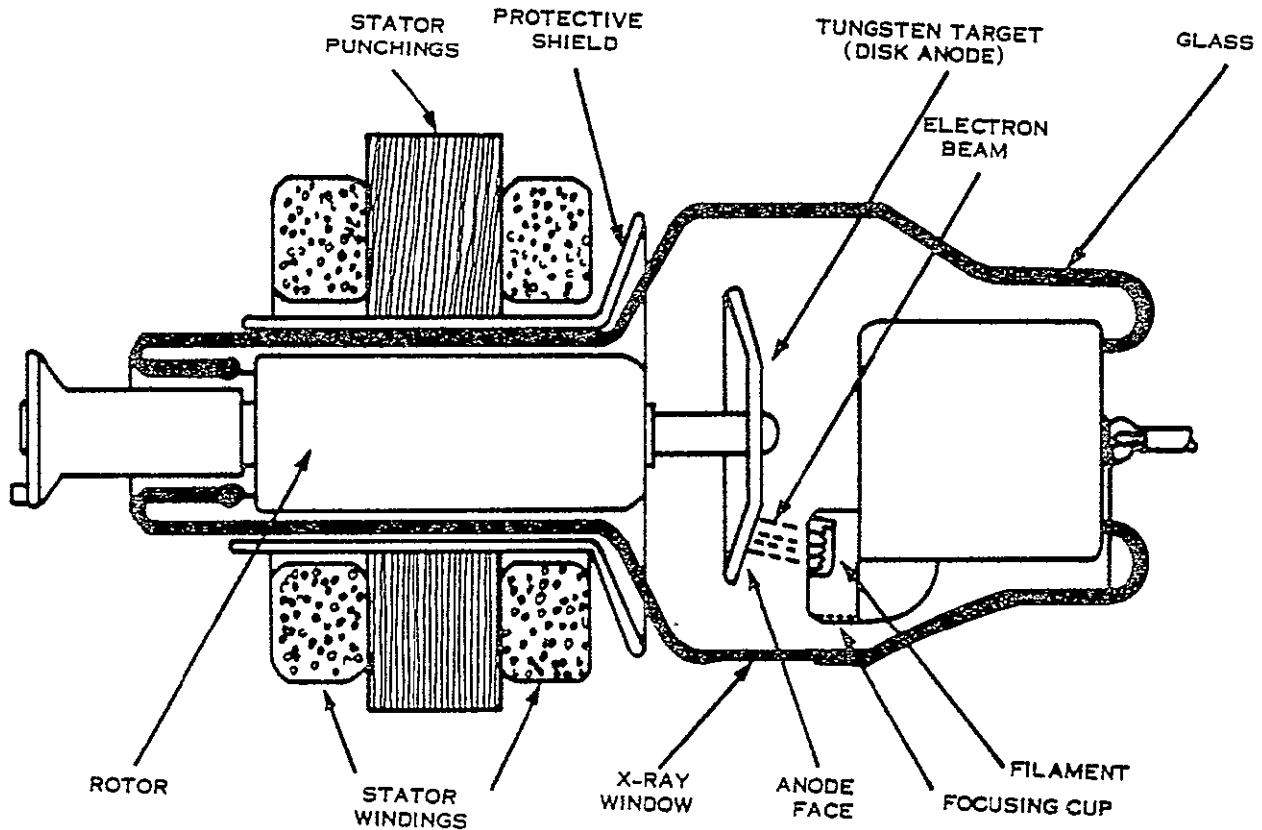


Figure I-1. Cross-Section of Typical X-ray Tube

expected to exhibit the desired gains in ductility over present large grain forms of Tungsten.

I.2 ASSUMPTIONS

In addition to the basic Study Assumptions reviewed in Section IV of Volume I, the following key assumptions have been made in the development planning:

- The experiments and tests, defined in Phase II and updated in this Phase, will result in a successful technique for producing Tungsten with a DBTT at and below room temperature via a space levitation, heat, melt, super-cool process.
- Sounding rocket, KC 135, drop tower as required, and Shuttle/Spacelab services will be available to meet development requirements.

- In-space power requirements for tungsten processing (25-70 Kw peak) will be available as needed.
- The availability of an on-orbit Tungsten processing facility, not requiring launch and recovery for each production flight was a late assumption in the Study, and is discussed in Volume I, Section IV.1.
- An initial Study Guideline (Section IV.1, Volume I) directed that our profitability analysis assume that each user bear the full cost of developing the Space Process utilized for producing his product. All four of the products under study were unattractive ventures under the combination of this assumption and derived economic data. The NASA C.O.R. suggested that this combination be noted as "Case A".

He further suggested that, since basic processes would have broader application than the individual products under study, it could likely be assumed that basic process proof-of-feasibility would be carried out under government funding. Users, therefore, would only bear those R&D costs that specifically provide prototype/pilot plant capability. The combination of this assumption and the same derived economic data as in the prior case is called "Case B". While some financial measures were very attractive in Case B, the "breakeven point" was still not favorable, and further assumptions led to "Case C". Assumptions for Case C include those of Case B, plus doubling of the market share and 20% decrease in unit manufacturing cost. The former is likely to be difficult, but possible, if the desired product performance is achieved. The latter is possible, if a solar concentrator becomes available for heating of the Tungsten.

I.3 PRODUCT OBJECTIVES

The primary product objective is to utilize the space environment to aid in producing high purity tungsten with high temperature strength and, mainly, with ductility to withstand power impulse levels of 10^7 watts per square centimeter. These require DBTT at or below room temperature, and a yield strength of 20,000 psi (minimum) at 1100°C.

The secondary objective is to produce an X-ray tube using space-processed Tungsten which is capable of 30,000 standard exposures with less than 10% X-radiation fall-off.

I.4 PROCESS ALTERNATIVES AND BASELINE

The alternative process methods and key steps in the baseline approach selected for this Phase of Study have been derived in Phase II. These are shown in Figure I-2. Those major alternatives and decisions left unresolved in Phase II, due to lack of critical phenomenological or process data, have for the most part, been resolved by assumptions for purposes of this phase of study. It must be noted, however, that a high degree of judgement has been exercised in making the required selection.

The technical decisions and unknowns associated with this selection are given in Figure I-3.

The unknowns listed in Figure I-3 are those which form the basis for the subsequent definition of experiment and test Work Elements in the R&D portion of the Work Break-down Structure. Current Tungsten Processing programs in GE's Space Sciences Laboratory are addressing such unknowns as residual gas levels, effects of other variables on amount of interstitials, etc. Resolution of any such unknowns through current or other future programs are not accounted for here, but will, of course, influence the future application of this Study's findings.

Baseline process data defining key requirements for the selected process are shown in Section II.2.5.

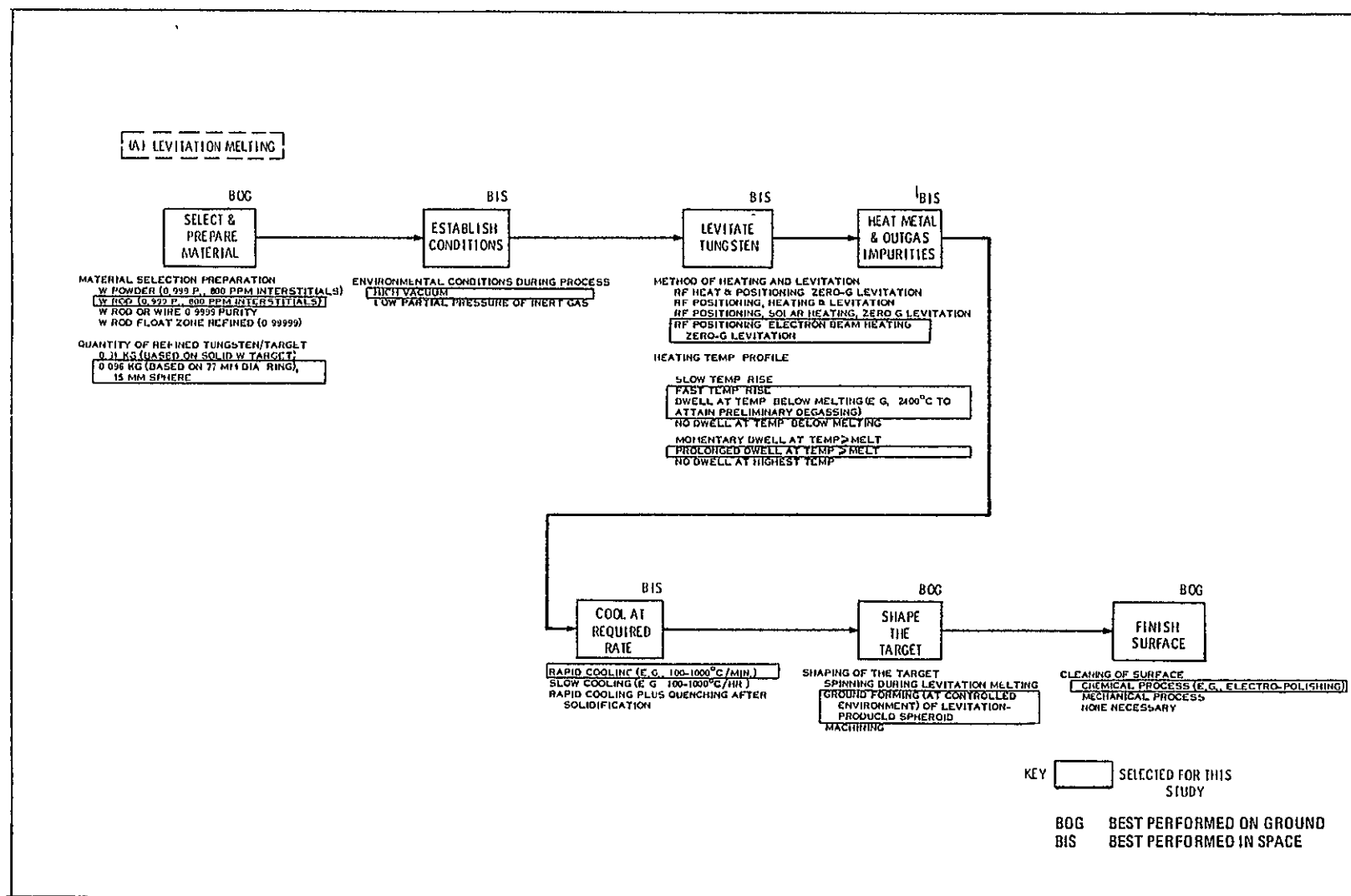


Figure I-2. Definition of Best Implementation Approach for High Purity Tungsten X-Ray Target Processing

<u>DECISIONS</u>	
<u>Decision Area</u>	<u>Current Preferred Method</u>
1. Choice of atmosphere for de-gassing	Hard Vacuum
2. Choice of heating system	RF Coil, Plus Electron Beam, Rapid Heat
3. Choice of levitation system	RF Coil
4. Choice of Cooling System	Rapid Cool (radiation)
5. Choice of tungsten rod characteristics	Rod, 0.999 pure, 800 PPM Interstitials
<u>*Unknowns which require experiments and tests for resolution</u>	
1. Influence of initial tungsten purity	
2. Residual gases in tungsten and their partial pressures at various degas temperatures.	
3. Optimum temperature for degassing.	
4. Specific degassing chemical reactions in the degassing environment.	
5. Optimum duration (dwell time) of degassing step(s).	
6. Tungsten vapor pressure emissivity.	
7. Best combination of solid state and molten state degassing durations, temperatures, and environments.	
8. Effects of items 1-7 on amount of residual interstitial materials, grain size and shape.	
9. RF heating and levitation power requirements.	
10. Tungsten response to RF heating (Skin depth, coupling)	
11. Degree of supercooling obtainable with tungsten.	
12. Rate of tungsten grain growth and nucleation on cooling from melt.	
13. Need for gas or liquid quench.	
14. Solubility of tungsten contaminants.	

Figure I-3. Current Decisions and Unknowns* in Tungsten X-Ray Target

SECTION II

DEVELOPMENT PROGRAM

The frame work upon which development tasks, schedules, costs, equipment and facility needs, etc. are constructed, is the Work Breakdown Structure (WBS). While relatively unfamiliar outside the Aerospace/Military communities, it is felt to provide sufficiently valuable insight to program planning to warrant its introduction into this commercial product study.

We have, however, deviated from the usual WBS content. The long development effort for products under study, the need for both Space and Ground Processing steps, the obvious comparisons between familiar ground processes and the "new" Space-involving process led us to establish a WBS based on process steps, rather than on equipment. Thus subsequent analyses could easily compare value-added versus cost-added for any process step.

This section of the report details the WBS for the Tungsten processing program and summarizes the Work Element Descriptions, Work Element Resource Requirements, and Resource costs. Finally, it assembles the Development Schedule.

II.1 WORK BREAKDOWN STRUCTURE

The Work Breakdown Structure against which the development and production tasks are organized is shown in Figure II-1 A&B. Figure II-1A depicts the configuration of the WBS at the top level, while II-1B delineates the detailed structure. The development effort which is documented in over 110 pages of Work Element Descriptions, Work Element Resource needs and Resource Costs, is summarized in Section II.2.

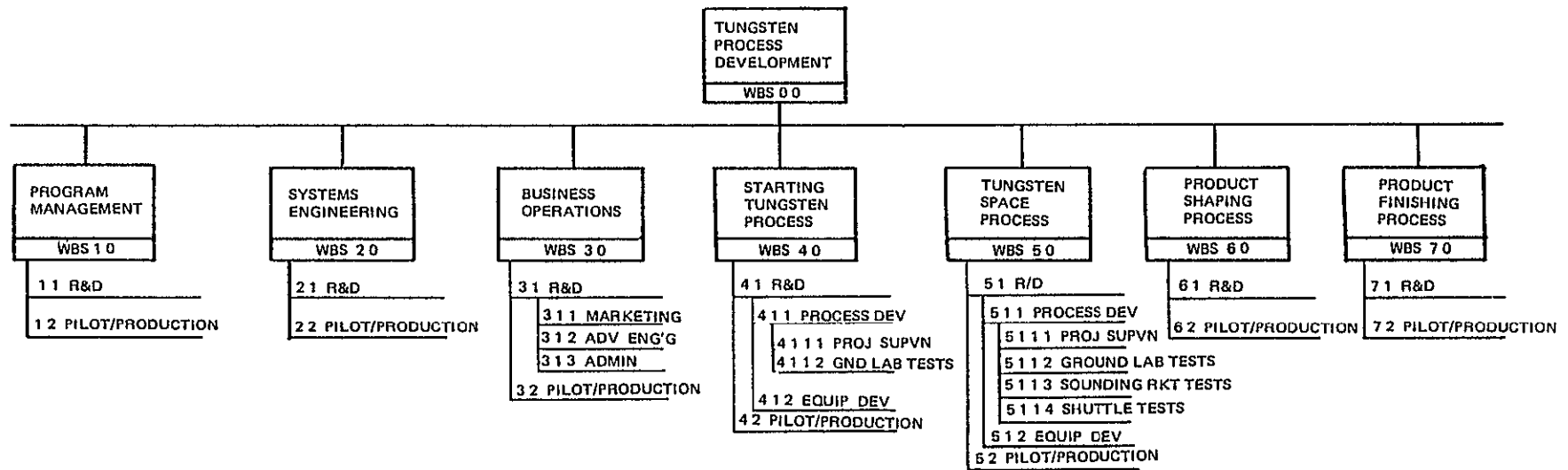


Figure II-1A. Work Breakdown Structure

- 1.0 Program Management
 - 1.1 Prog. Mgmt-R&D
 - 1.2 Prog. Mgmt-Pilot/Prod.
- 2.0 System Engineering
 - 2.1 Sys. Eng'g-R&D
 - 2.2 Sys. Eng'g-Pilot/Prod.
- 3.0 Business Operations
 - 3.1 Bus. Opers-R&D
 - 3.1.1 Marketing
 - 3.1.2 Adv. Eng'g
 - 3.1.3 Admin. (legal, finance, etc.)
 - 3.2 Bus. Opers-Pilot/Prod.
- 4.0 Starting Tungsten Process Step
 - 4.1 Process & Equip. Dev. (R&D)
 - 4.1.1 Process Development
 - 4.1.1.1 Project Supervision
 - 4.1.1.2 Ground Lab Tests (Test 1)
 - 4.1.1.2.1 Composition of Starting Tungsten
 - 4.1.1.2.2 Interstitial Content
 - 4.1.1.2.3 Gas Content
 - 4.1.1.2.4 Grain Size
 - 4.1.1.2.5 Grain Shape
 - 4.1.1.2.6 Microhardness
 - 4.1.1.2.7 Metal Characterization
 - 4.1.1.2.8 Tensile Strength
 - 4.1.1.2.9 Particle Size
 - 4.1.1.2.10 Oxygen Content/Removal
 - 4.1.1.2.11 Process Selection
 - 4.1.2 Equip. Dev. & Test (R&D)
 - 4.2 Starting Tungsten Preparation (Pilot/Prod.)
- 5.0 Tungsten Space Processing Step
 - 5.1 Process & Equip. Dev. (R&D)
 - 5.1.1 Process Development
 - 5.1.1.1 Project Supervision
 - 5.1.1.2 Ground Lab Studies
 - 5.1.1.2.1 Levitation of Tungsten (Test 2)
 - 5.1.1.2.2 Electron Beam Heating (Test 3)
 - 5.1.1.2.3 Vacuum degas with Levitation (Test 4)
 - 5.1.1.2.4 Levitation, Heat & Melt at 1-G (Test 5)
 - 5.1.1.3 Sounding Rocket Experiments
 - 5.1.1.3.1 Limited Duration Zero-G Test of Positioning Devices (Test 6)
 - 5.1.1.3.2 Limited Duration Zero-G Test of Heating & Vacuum Degas (Test 7)
 - 5.1.1.3.3 Limited Duration Zero-G Degas, Melt & Supercool (Test 8)
 - 5.1.1.4 Shuttle Experiments
 - 5.1.1.4.1 Long Duration Zero-G Space Process Test (Test 9)
 - 5.1.1.4.2 Prototype Space Process Demonstration (Test 10)
 - 5.1.1.4.3 Evaluation of Prototype Space Process (Test 11)
 - 5.1.2 Equipment Development & Test (R&D)
 - 5.1.2.1 Chamber/Shield/Structure, etc.
 - 5.1.2.2 Space Heat, Melt, Position Equip.
 - 5.1.2.3 Power Conditioning
 - 5.1.2.4 Instrumentation & Controls
 - 5.1.2.5 Vacuum, Gas & Coil Cooling Supply Systems
 - 5.2 Tungsten Space Process (Pilot/Production)
- 6.0 Tungsten Product Shaping Process
 - 6.1 Tungsten Product Shaping Process (R&D)
 - 6.2 Tungsten Product Shaping Process (Pilot/Prod.)
- 7.0 Tungsten Product Finishing Process
 - 7.1 Tungsten Product Finishing Process (R&D)
 - 7.2 Tungsten Product Finishing Process (Pilot/Prod.)

Figure II-1B. Tungsten X-Ray Target Development Work Breakdown Structure

The technical and business assessment of the in-space Tungsten processing opportunity requires that all elements of work required, from raw materials to finished product be examined, costed, and assessed. The main process steps provide a suitable framework for collecting tasks and costs over that sequence of events, and this approach tends to assure that no major business costs are overlooked. Four major process steps are defined for Tungsten processing:

Starting Tungsten Preparation (WBS 4.0)

Tungsten Space Processing (WBS 5.0)

Tungsten Product Shaping (WBS 6.0)

Tungsten Product Finishing (WBS 7.0)

Attention to the product shaping process is postponed for the present time, as explained in Section II.2.6.

To the above four elements, work elements for integrating and planning the development and pilot/production program are added as follows:

Program Management (WBS 1.0)

System Engineering (WBS 2.0)

Business Operations (WBS 3.0)

Each major WBS element is divided into R&D and Pilot/Production phases, with the R&D phase ending at completion of a prototype capability. Work and cost summaries can thus be obtained either for a process step or for a particular phase. The ability to summarize a process step facilitates comparison of the cost of a process relative to others, assessment of alternatives (e.g., buying prepared tungsten charges for use in space processing rather than preparing them in-plant), the

examination of value added in each process step and examination of the option to sell as a product, the output of a particular process step.

II.2 WORK ELEMENTS (WORK TO BE DONE)

The development of a ground/space/ground process, such as that pictured in Figure II-2 for preparation of X-Ray targets of low DBBT tungsten using a space processing facility, can be categorized into the following top level Work Elements:

- 1.0 Program Management
- 2.0 System Engineering
- 3.0 Business Operations
- 4.0 Raw Tungsten Processing
- 5.0 Tungsten Space Processing
- 6.0 Product Shaping
- 7.0 Product Finishing

These elements apply to both the development (R&D) phase and production phase.

The R&D effort is largely concentrated in element 5.0, Tungsten Space Processing, and this development plan accordingly emphasizes that area of work. A description of the work to be done in each work element is given in the following paragraphs.

The development program includes a series of major experiments and tests as shown in Figure II-3A. The Sounding Rocket and Shuttle tests are summarized in Figure II-3B.

II.2.1 PROGRAM MANAGEMENT (WBS 1.0)

Program Management in the R&D phase will include the definition of development tasks and schedules, arranging for and controlling the resources needed, and maintaining a management liaison with the parties involved. These parties will include the tungsten

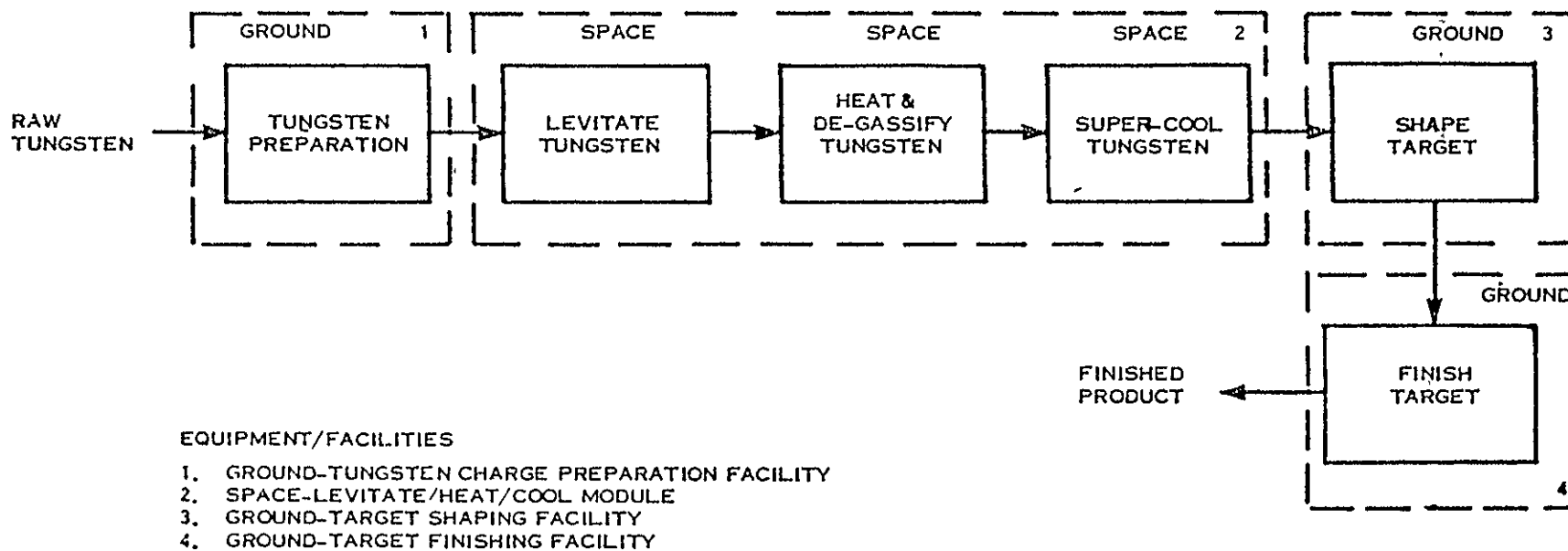


Figure II-2. Tungsten X-Ray Target Processing Ground/Space Process Steps & Facilities

		WBS
Process Phenomenology	1. Initial Vacuum Degassing Studies Ground Lab	5.1.1.2.1
	2. Levitation of Solid Tungsten, Initial Studies Ground Lab	5.1.1.2.1
	3. Electron Beam Heating, Initial Studies Ground Lab	5.1.1.2.2
Levitation Evaluation	4. Vacuum Degassing with Levitation Ground Lab	5.1.1.2.3
	5. Levitation, Melting, Heating at One "G" Ground Lab	5.1.1.2.4
Verification of Zero-G Equipment	6. Design Test of Positioning Devices for Space Operations Drop Tower, KC 135, Sounding Rocket	5.1.1.3.1
	7. Design Test of Heating, Degassing System for Space Operation Sounding Rocket	5.1.1.3.2
	8. Design Test of Heating, Degassing, Melting, Supercooling System for Space Operation Sounding Rocket	5.1.1.3.3
Pilot/Prototype Type	9. Design Test of Total Space Processing System Shuttle	5.1.1.4.1
	10. Proof Test of Total Space Processing System Shuttle	5.1.1.4.2
	11. Evaluation Tests of Tungsten Products Operational Test Lab (Ground)	5.1.1.4.3

Figure II-3A. Tungsten Test Series

WBS NO	Test	Expt No	Power Required (KW)	Expt Weight (Kg)	Expt Vol (M ³)	Fit Date (Year)	Total Expt Duration	Fit Crew Support Required (Man Hrs)	Flight Vehicle	Data Transmission Requirements	Data Processing Requirements	Energy Req'd (KWH)
5 1 1 3 1	Positioning & Levit Test	6	4	100	0.2	76	4 10 min	none	SR 1	TBD	TBD	0.5
5 1 1 3 1	Positioning & Levit Test	6	4	100	0.2	76	4 10 min	none	SR 2	TBD	TBD	0.5
5 1 1 3 2	Heat & Degas Test	7	4	200	0.2	77	4 10 min	none	SR 3	TBD	TBD	0.5
5 1 1 3 2	Heat & Degas Test	7	4	200	0.2	77	4 10 min	none	SR 4	TBD	TBD	0.5
5 1 1 3 3	Melt & Supercool Test	8	4	200	0.2	78	4 10 min	none	SR 5	TBD	TBD	0.5
5 1 1 3 3	Melt & Supercool Test	8	4	200	0.2	78	4 10 min	none	SR 6	TBD	TBD	0.5
5 1 1 3 3	Melt & Supercool Test	8	4	200	0.2	79	4 10 min	none	SR 7	TBD	TBD	0.5
5 1 1 4 1	Prototype Process Test	9	4.7 KW	545	1	80	120 Hrs	14 Hrs	SL 1	none	none	100 KWH
5 1 1 4 1	Prototype Process Test	9	4.7 KW	545	1	81	120 Hrs	14 Hrs	SL 2	none	none	100 KWH
5 1 1 4 2	Prototype Proof Test	10	20.45 KW	900	2.5	82	120 Hrs	14 Hrs	SL 3	none	none	400 KWH

SR = SOUNDING ROCKET

SL = SHUTTLE/SPACELAB

Figure II-3B. Flight Test Requirements for Tungsten Processing R&D

research laboratory, tungsten product manufacturers, NASA centers, the tungsten space system contractor, and NASA contractors. While each development task will include project supervision of that work, Program Management will provide for the overall management of all aspects of the program. Reports, presentations, special documents and plans are also included in Program Management. When the production phase is instituted, Program Management will be phased out and the routine planning and control activities will be handled by administrative and production control functions of the business. Some project engineering service will be required to handle shuttle services and interfaces.

II.2.2 SYSTEM ENGINEERING (WBS 2.0)

In the R&D phase, System Engineering will be required to establish requirements and specifications for the overall ground-space-ground process to be designed, and to conduct tests of overall processes. As development tests eliminate the present unknowns and technology gaps, System Engineering will convert these findings to a specific prototype system design (ground-space) and ultimately to a pilot/production facility design as portrayed in Figure II-4. In commercial terms, this is a combined plant engineering and product engineering activity, with the added dimensions of space vehicle/payload interfacing and orbital operations requirements. The output of the R&D System Engineering effort will be overall process and materials specifications and process equipment design requirements. In the production phase, System Engineering will be phased out and this work will be assumed by Advanced Engineering.

II.2.3 BUSINESS OPERATIONS (WBS 3.0)

Business Operations in the R&D phase will be concerned with business preparations in anticipation of a successful development effort and initiation of production.

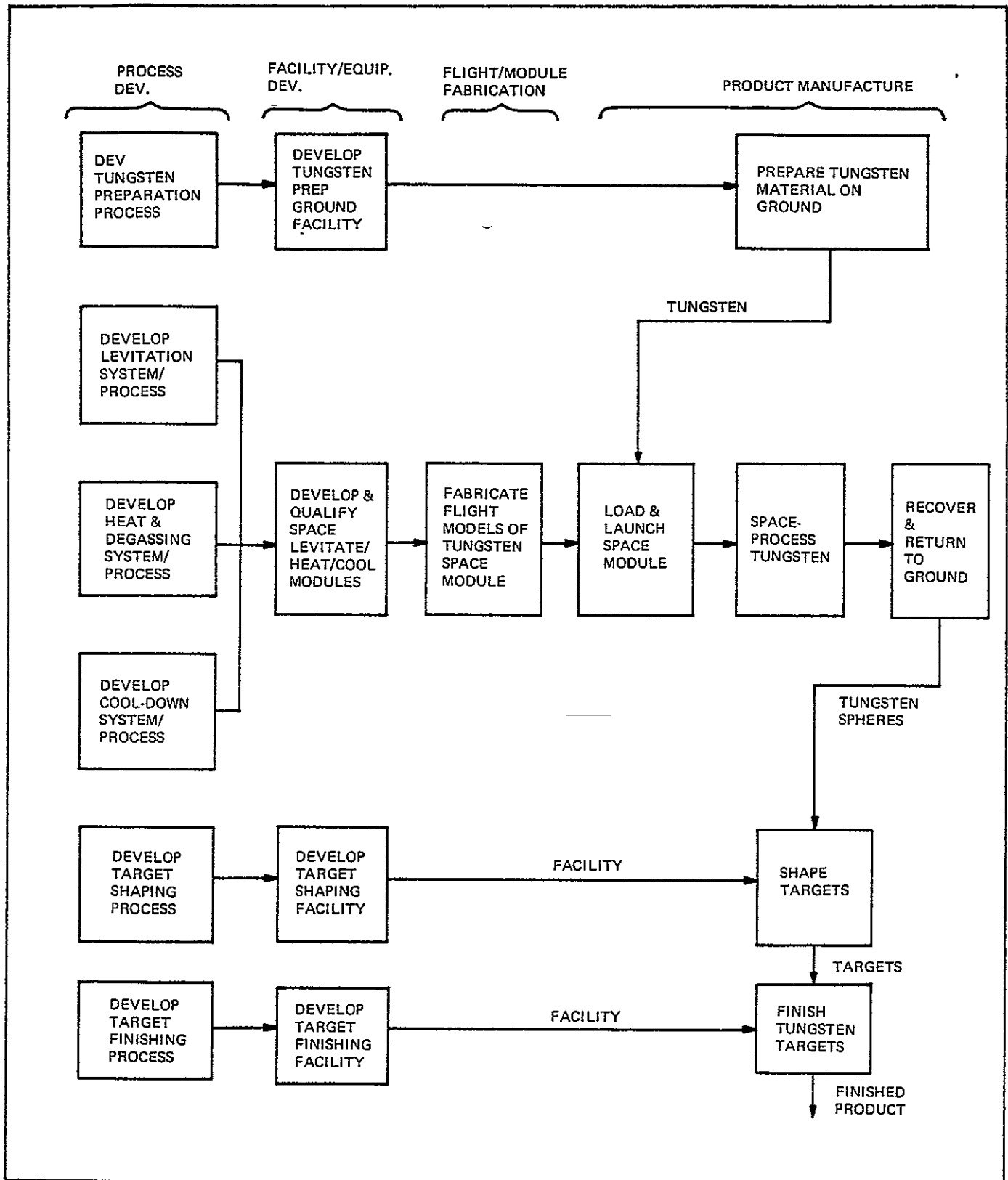


Figure II-4. Tungsten Target Production-Development & Mission Profile

Business planning must be done continuously as a basis for investment decisions as R&D results are obtained. Three areas of Business Operations are described as follows.

WBS 3.1.1 Marketing

Development program initiation is necessarily based on very early estimates of business viability and financial returns. During the R&D activity, Marketing must continuously analyze the potential market, market share, anticipated orders, product offerings, gross margins, product costs, profits, etc. in order to confirm or modify earlier plans. As the time of pilot production approaches, Marketing will prepare sales literature, preliminary catalog data, and price data as the basis for customer contacts. The product distribution system will be designed and an appropriate sales organization will be initiated. Demonstrations of product characteristics and performance will be conducted using samples from early tests and prototype/pilot runs to convince customers of product advantages and to establish a preliminary seller/purchaser understanding. Advance orders will be solicited as early as possible in the R&D phase to reduce the risk associated with a commitment to build production facilities. When the production phase begins, Marketing will conduct routine order processing, cataloging, product service, product planning, and sales engineering activities as well as future market/business planning.

WBS 3.1.2 Advanced Engineering

Advanced Engineering will be relatively quiescent during the R&D phases since the R&D System Engineering and R&D Experiment and Test tasks will be accomplishing that function. A limited amount of second generation technical investigation will be done to explore opportunities which lie beyond the scope of the R&D effort. These findings may have an effect on the direction of the R&D effort. When the production phase begins, Advanced Engineering work will increase, to develop improvements

on the pilot/production design and to introduce new processes and facilities as suggested by Marketing plans.

WBS 3.1.3 Financial, Legal and Relations Support

In the R&D phase, the Finance, Legal and Relations functions will participate with Marketing in the preparation and critique of business plans, and recommending of steps to be taken by management to prepare for production. The timing and amount of investments will be critical, with pressures to move quickly to establish a market position, and pressures to postpone action, to reduce financial risk. Relations will be concerned with staffing of R&D positions and planning for production staff. Legal will address the contract/subcontract terms anticipated for production, and the insurance/indemnity/warranty provisions that are planned to be used. This work will include establishing of the terms for using NASA shuttle services, and the associated manufacturer/NASA liabilities.

II.2.4 RAW TUNGSTEN PROCESS STEP (WBS 4.0)

An R&D effort is required to establish the characteristics of the raw (starting) tungsten which is to be used for space processing. The effort will define chemical purity, size and shape of the tungsten charges which will be fed to the tungsten furnace for refinement. A number of optional grades of material exist, with varying degassing and impurity characteristics, and commercial prices. Therefore, a series of tests will be conducted to arrive at a preferred starting tungsten specification. That series is represented by the Work Element 4.1.1.2 of the WBS, and Figure II-5 provides the work element description, resource needs, and resource costs. The process and equipment for preparing the tungsten charge must also be devised (e.g. a powder metallurgy process with die forming, if chosen, requires definition of the powder, the forming process, the die design, the cleaning/decontamination, etc.) In addition, the tungsten handling and transport methods and environmental protection must be established. In the production phase, a facility for production of starting tungsten will be required, with an appropriate throughput.

TASK DESCRIPTION		
TASK TITLE Starting Tungsten - Ground Lab Studies		
WBS NO. 4.1.1.2	PREPARED BY PTS	DATE 9/9/74
1. REQUIRED OUTPUT: Selection of the tungsten characteristics for starting tungsten for space processing (using pressed and sintered or wrought tungsten) - chemical composition - Interstitials - Gas Content - Grain Size - Microhardness - Metal characterization - Tensile strength and ductibility - Particle size (powder) - Oxygen content (powder)		
2. REQUIRED INPUT: Findings of degassing experiments conducted under NAS 8-29879 (GE-SD/SSL) as defined for wrought tungsten.		
3. DESCRIPTION OF EFFORT: Conduct a series of ground lab tests, (one series for each output item above) as defined by Tasks 4.1.1.2.1 - 4.1.1.2-11.		
4. PERFORMANCE PERIOD 3Q1974 through 4Q1975 (15 months)		
PERFORMANCE RESPONSIBILITY:		APPROVAL
Tungsten Research Lab		

NOTE CONTINUE NUMBERED ITEMS ON SEPARATE SHEET AS REQUIRED

Figure II-5. Task Description, Resources & Costs,
Starting Tungsten - Ground Lab Tests

TASK RESOURCE REQUIREMENTS		
TASK TITLE Starting Tungsten - Ground Lab Studies		
WBS NO. 4.1.1.2	PREPARED BY PTS	DATE 9/74
1. PURCHASED MATERIALS: (INCLUDE ASSUMPTIONS)		
1. Commercial stock tungsten 99.0%, 99.9% 2. Tungsten Alloys (up to 1% Mo, Hf, Re, etc.)		
2. PURCHASED SERVICES: (INCLUDE ASSUMPTIONS)		
1. Physical characterization. 2. Chemical characterization. 3. Metallurgical characterization.		
3. EQUIPMENT: (INCLUDE ASSUMPTIONS)		
1. Vacuum fusion (platinum or iron bath) with mass spectrometer. 2. Conductometric. 3. Reichert metallographic microscope. 4. Metallographic preparation. 5. X-ray diffractometer. 6. Electron probe microanalyzer 7. Vacuum-degassing facility with mass spectrometer		
4. FACILITIES (INCLUDE ASSUMPTIONS)		
1. Lighting 2. Electricity 3. Laboratory Space 4. Heat		
		APPROVAL:

NOTE: CONTINUE NUMBERED ITEMS ON SEPARATE SHEET AS REQUIRED.

Figure II-5. Task Description, Resources & Costs, Starting Tungsten - Ground Lab Tests (Cont'd.)

Figure II-5. Task Description, Resources & Costs, Starting Tungsten - Ground Lab Tests (Cont'd.)

WORK ELEMENT COSTS							
WORK ELEMENT NO. 4.1.1 2		WORK ELEMENT TITLE Starting Tungsten R&D - Ground Lab Studies					
1 ACT. NO.	2 ACTIVITY	3 LABOR COST	4 PURCHASED MATERIALS COST	5 SERVICES COST	6 EQUIPMENT COST	7 FACILITIES COST	8 TOTAL COST
4.1.1.2.1	Chemical Composition of Starting Tungsten	1500	90	1500	-	-	3090
4.1.1.2.2	Interstitial Content of Starting Tungsten	1000	30	1300	-	-	2330
4.1.1.2.3	Gas Content of Starting Tungsten	1000	30	300	-	-	1330
4.1.1.2.4	Grain Size of Starting Tungsten	1500	90	3500	-	-	5090
4.1.1.2.5	Grain Shape of Starting Tungsten	1500	90	3500	-	-	5090
4.1.1.2.6	Microhardness Testing of Starting Tungsten	1500	90	800	-	-	2390
4.1.1.2.7	Metal Characterization Starting Tungsten	1500	90	1500	-	-	3090
4.1.1.2.8	Tensile Strength & Ductibility of Starting Tungsten	1500	90	1500	-	-	3090
4.1.1.2.9	Particle Size Determination	1000	30	1000	-	-	2030
4.1.1.2.10	Oxygen Content	1000	30	1000	-	-	2030
4.1.1.2.11	Process Selection	15440	-	-	-	-	15440
TOTALS		\$28.44K	\$0.66K	\$15.91	-	-	\$45K

II.2.5 TUNGSTEN SPACE PROCESSING (WBS 5.0)

This is the most challenging part of the overall R&D effort. A number of basic phenomenology and process technique studies are required to fill present knowledge gaps for the selected process. These require studies of:

- tungsten levitation
- electron beam heating
- vacuum degassing during levitation
- levitation, heating and melting at 1-G
- heating and vacuum degassing at 0-G
- de-gas, melt and supercooling at 0-G
- positioning methods at 0-G

The effort will be directed at specification, fabrication and testing of a prototype/pilot space facility with a unit charge capacity in the order of 1 kg or more, with associated positioning coil, (RF), coil cooling, tungsten feed and retrieval, chamber and shielding, electron beam gun, and appropriate sensors and controls. Key areas of consideration are:

- Very high power requirements (up to 50 Kw input peak)
- high RF field intensity
- heat rejection
- safety considerations

The basic tungsten levitation, heat, degas, melt, and supercool processes and equipment will be tested initially at 1-G. As soon as these equipment techniques are

understood, experiments such as those listed in Figure II-6 will be conducted using small specimens (e.g. 0.5 cm diameter) in sounding rocket and early shuttle flights to confirm the expected tungsten product characteristics and equipment approaches. Figure II-7 provides a representative work element description, resource requirements and resource costs for the such sounding rocket test. Scale-up of equipment designs (e.g. to the 1-Kg charge range) will be done as small-specimen confidence is established, and then a shuttle prototype proof demonstration will be conducted to prove the design. Figure II-8 defines a WBS element for such a test. Baseline process requirements for both a typical experiment and production are given in Figure II-9. Successful prototype operation and a confirmed product demand will form the basis for initiation of routine production at pilot or greater capacity. Figure II-10 depicts the scale-up version of the modular tungsten processor, which presents the potential for direct evolution to the production phase. In reviewing equipments potentially capable of being adapted from laboratory use to space process Tungsten, we reviewed more than 40 types and documented their capabilities as in Figure II-11, 12 and 13. The R&D effort will not address the raw power source, except to establish a suitable power conditioning interface with a source provided by NASA. Later, production designs may provide for an integrated high power heat source, such as a solar collector/solar furnace.

A summary of our current view on those equipments most logical for a continuing program to develop and produce space processed tungsten is given in Figure II-14, which lists the items needing some development and tallies the quantities of the equipments needed at each major stage of the program. Special requirements on safety and waste control in the processing of tungsten must be provided for in both experimental and production phases. Figure II-15 lists key provisions in those areas.

II.2.6 TUNGSTEN PRODUCT SHAPING (WBS 6.0)

The basic tungsten product as received from the space processing facility will be a sphere shape of, 5 cm diameter, although at some later time, it may be feasible

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FACILITY	EXPERIMENTS AND VERIFICATION TESTS	OBJECTIVES	EXPERIMENT AND TEST REQUIREMENT (SUMMARY)
GROUND LAB	Initial vacuum degassing experiments on Degassing times vs. temperature type and quantity of gases and other impurities degassing effects on mechanical properties, interstitials content grain size and shape To aid in selection of initial tungsten quality	Degassing rates of various impurities. Effects of temperature, vacuum and gas partial pressures Initial tungsten purity	Standard Ground Lab with vacuum induction furnace, RF generator, mass spectrometer gas sampling system, process instrumentation materials and gas analysis equipment spectroscopy Specimens of grades of tungsten 2 1/2 weeks per specimen Manual control
	Initial solid tungsten positioning control experiments to determine RF coil design power requirements	Design data for positioning, control RF coil	Standard Ground Lab RF generator, positioning/control coil vacuum chamber optical pyrometer Tungsten specimens - 10 to 1000 grams Photographic equipment Process instrumentation 3 1/2 hours per run Manual
	Experiments on electron beam heating of tungsten to establish heating efficiency and aid in selection of initial tungsten quality	Selection and design data for tungsten heating system Effects of initial tungsten purity	Standard Ground Lab electron beam gun x ray protection, vacuum chamber, 10KV (1 2 AMP) power supply specimen fixturing temperature and power instrumentation mass spectrometer, specimens of tungsten (various grades) materials analysis equipment 4 to 5 hours per specimen Manual
	Experiments on vacuum degassing with levitation to compare RF positioning and heating vs. RF positioning with electron beam heating for degassing step Also determine amount and type of contaminant release as function of heater and dwell times Aid in selection of initial tungsten purity	Selection of system or combination of systems for heating positioning of tungsten Assessment of inter actions for combination system Effectiveness of degassing Effects of pre melt dwell and initial tungsten purity	Standard Ground Lab with vacuum system and levitation chamber RF levitation/positioning coil, electron beam gun various purity tungsten specimens specimen fixturing RF power supply (4 kW to 25 KW at 450 KHz) mass spectrometer gas sampling system process instrumentation, metallurgical characterization 4 1/2 hours per run Manual
ENGINEERING LAB	Levitation, heating melting test for feasibility of RF coil/electron beam as control and heater Also assess effects of vacuum and inert gas on tungsten evaporation Also preliminary supercooling experiment	Assessment of positioning, heating degassing, melting supercooling advantages Preliminary selection of process atmosphere Preliminary assessment of processed tungsten metallurgical and operational property gains	Standard Ground Lab, equipment as above plus inert gas system and copper or ceramic cooling crucible Also operational testing (Test X-ray tubes programmed test apparatus standard shielded test chamber etc) 4 1/2 to 5 hours per run plus 1 week characterization plus 15 days operational testing
DROP TOWER	Zero "G" verification test of positioning system	Assessment of positioning system and acquisition of design data.	Drop Tower test package of positioning device, tungsten specimen, caging system position monitoring instrumentation recorder, power supply and distribution photographic apparatus, measurement grid Automated Minimum test time 4-10 sec Telemetry or recording of data, recovery of test package and recorder data
KC 135	Zero "G" verification test of positioning system	Assessment of positioning system and acquisition of design data	KC 135 test package of positioning device, tungsten specimen, caging system position monitoring instrumentation recorder power supply and distribution photographic apparatus measurement grid Automated Minimum test time 20 to 40 seconds Telemetry or recording of data recovery of test package and recorder data

SOUNDING ROCKET	Zero "G" verification test of positioning system	Assessment of positioning system and acquisition of design data.	Sounding Rocket test package of positioning device, tungsten specimen, caging system, position monitoring instrumentation, recorder, power supply and distribution, photographic apparatus, measurement grid Automated Minimum test time 4 to 10 minutes Telemetry or recording of data, recovery of test package and recorder data
	Zero "G" preliminary verification tests of heating and degassing technique	Effectiveness of heating and degassing methods	Sounding Rocket, test package as above plus electron beam gun, increased power supply, gas sampling system and analyzer, inert gas system, Automated Minimum test time, 7 to 10 minutes Telemetry or recording of data, recovery of test package, processed sample, recorded data.
	Zero "G" preliminary verification tests of degassing,	Assessment of process effectiveness.	Sounding Rocket Test package as above plus further increased power supply Maximum size specimen Automated Minimum test time 8 to 10 minutes. Telemetry and recovery as above

Figure II-6. Experiments to Verify Selected Approach for High Purity Tungsten X-Ray Targets

TASK DESCRIPTION		
TASK TITLE Limited-Duration Zero G Testing of Positioning Device (Test 6)		
WBS NO. 5.1.1.3.1	PREPARED BY R. Hueschen	DATE 7/15/74
1 REQUIRED OUTPUT: Verification of the feasibility of the levitation positioning device in zero-G environment (short duration)		
2. REQUIRED INPUT: Results of Tasks 5.1.1.2.1-5.1.1.2.4 Approval of Sounding Rocket mission(s) (or Drop Tower or KC-135)		
3 DESCRIPTION OF EFFORT: - Design and fabricate test package for launch of experiment on sounding rocket (or KC-135 or Drop Tower) - Load, launch & fly experiment under zero G - Under zero-G, levitate and position specimen and record results - Recover test package and data and evaluate test results - Establish positioning and stability feasibility and limitations Basis - 2 flight, SR-1, SR-2		
4 PERFORMANCE PERIOD 2Q75 to 2Q77		
PERFORMANCE RESPONSIBILITY:		APPROVAL

NOTE CONTINUE NUMBERED ITEMS ON SEPARATE SHEET AS REQUIRED

Figure II-7. Task Description, Resources & Costs, Limited Duration Zero G Testing of Positioning Device

TASK RESOURCE REQUIREMENTS		
TASK TITLE Limited Duration Zero G Testing of Positioning Device (Expt 6)		
WBS NO 5.1.1.3.1	PREPARED BY R. Hueschen	DATE 7/16/74
1. PURCHASED MATERIALS: (INCLUDE ASSUMPTIONS) a) Tungsten-Selected From Previous Tests		
2. PURCHASED SERVICES: (INCLUDE ASSUMPTIONS) a) Aerobee Sounding Rocket-Prelaunch and Recovery. b) Telemetry-critical "charge" positioning.		
3. EQUIPMENT: (INCLUDE ASSUMPTIONS) a) Black Brant Payload Container with Fixtures to Cage Sample-Ascent/Descent. b) RF Coil, Positioning Fixture & Power Integrated with Container. c) "Charge" Loading & Unloading-Plus Power. d) Instrumentation to Record Position Accuracy Plus Power. e) Photography to Record Positioning Accuracy Plus Power.		
4. FACILITIES (INCLUDE ASSUMPTIONS) a) Laboratory for Characterization, Evaluation.		
		APPROVAL:

NOTE: CONTINUE NUMBERED ITEMS ON SEPARATE SHEET AS REQUIRED.

Figure II-7. Task Description, Resources & Costs, Limited Duration Zero G Testing of Positioning Device (Cont'd.)

WORK ELEMENT COSTS							
WORK ELEMENT NO. 5 1.1.3.1		WORK ELEMENT TITLE Limited Duration Zero-G Positioning Test					
1 ACT. NO.	2 ACTIVITY	3 LABOR COST	4 PURCHASED MATERIALS COST	5 SERVICES COST	6 EQUIPMENT COST	7 FACILITIES COST	8 TOTAL COST
1.	Design fab and test of experiment packages (2 flights) and pre-flight test	2K	-	27K	-	-	229K
2.	Sounding Rockets Flights (2)	-					
	- Sounding Rockets	-	312K	-	-	-	312K
	- Flight Support (NASA)	-	-	94K	-	-	94K
3.	Post-flight test (2 flights)	2K	-	63K	-	-	65K
TOTALS		4K	312K	384K	-	-	700K

Figure II-7. Task Description, Resources & Costs, Limited Duration Zero G Testing of Positioning Device (Cont'd.)

TASK DESCRIPTION		
TASK TITLE Shuttle Experiment - Prototype Design & Test (Test 9)		
WBS NO. 5.1.1.4.1	PREPARED BY RH	DATE 8/74
1. REQUIRED OUTPUT:		
- Design of prototype tungsten space processing facility and confirmation of design via Shuttle/Spacelab tests of long duration (hours) - Prototype space processing facility		
2. REQUIRED INPUT:		
- Results of Tasks 5.1.1.3.1 to 5.1.1.3.3 (Sounding Rocket Tests) - Shuttle arrangements, including Power Kit (up to 30 KW peak input)		
3. DESCRIPTION OF EFFORT:		
- Design, fabricate and ground test the prototype tungsten processing facility for Shuttle/Spacelab experiment (scale-up from sounding rocket tests in 5.1.1.3) - Load, launch and fly experiment(s) on Shuttle/Spacelab (number of flights to be determined) - Evaluate test package performance, establish prototype process and equipment specifications (positioning, heat, degas, melt, cool, supercool, retrieve, power requirements, product characteristics, etc.)		
4. PERFORMANCE PERIOD		
1Q79 - 4Q82		
PERFORMANCE RESPONSIBILITY: Systems Contractor/Research Lab/Prod. Mfr.		APPROVAL:

NOTE. CONTINUE NUMBERED ITEMS ON SEPARATE SHEET AS REQUIRED

Figure II-8. Task Description, Resources and Costs, Shuttle Experiment - Prototype Design & Test

TASK RESOURCE REQUIREMENTS		
TASK TITLE Shuttle Experiment - Prototype Design & Test (Test 9)		
WBS NO. 5.1.1.4.1	PREPARED BY GW	DATE
1. PURCHASED MATERIALS (INCLUDE ASSUMPTIONS) - Miscellaneous raw materials for equipment fabrication. - Tungsten processing samples.		
2. PURCHASED SERVICES (INCLUDE ASSUMPTIONS) - Shuttle transport and support (NASA) - Payload design, integration and test - Post flight analysis		
3. EQUIPMENT (INCLUDE ASSUMPTIONS) - Measurement and recording equipment - Power conditioning equipment - Process control equipment		
4. FACILITIES (INCLUDE ASSUMPTIONS) Office, Laboratory and Shop facilities.		
		APPROVAL:

NOTE CONTINUE NUMBERED ITEMS ON SEPARATE SHEET AS REQUIRED.

Figure II-8. Task Description, Resources and Costs, Shuttle Experiment - Prototype Design & Test (Cont'd.)

WORK ELEMENT COSTS							
WORK ELEMENT NO. 5.1.1.5.1		WORK ELEMENT TITLE Shuttle Experiment Prototype Design & Test (Test 9)					
1 ACT. NO.	2 ACTIVITY	3 LABOR COST	4 PURCHASED MATERIALS COST	5 SERVICES COST	6 EQUIPMENT COST	7 FACILITIES COST	8 TOTAL COST
1.	Equipment design and fab	140K	50K	100K	50K	-	340K
2.	Quality Control/Space Qual	-	-	50K	-	-	50K
3.	Shuttle Flight Payload Design, Fab & Support	100K	25K	650K	250K	-	1025K
4.	Post Flight Analysis	60K	-	50K	-	-	110K
5	Shuttle Services (NASA) Space Charges - 2 Flights	-	-	871K	-	-	871K
TOTALS		300K	75K	1721K	300K	-	2396K

Figure II-8. Task Description, Resources and Costs, Shuttle Experiment - Prototype Design & Test (Cont'd.)

<u>Item</u>	<u>Experiment</u>	<u>Production</u>
Charge size	1 cm sphere diameter, .01 Kg	5 cm sphere diameter, 1.25 Kg
Preheating	None	None
Insertion	Mech. or Electromag- netic	Mech. or Electromag- netic
Heating Rate		
High	10-100°C/sec	10-100°C/sec
Low	5-10°C/sec	5-10°C/sec
Time to Dwell	1-2 min.	1-10 min.
Time at Dwell (Solid)	0	10-20 min.
Temperature, 1st Dwell	-	2400-3200°C
Time to melt, superheat	0	2-5 min.
Temperature, 2nd Dwell	3420°C	3420°C
Environment during heat	(10^{-3} N/M ² Vacuum or) (Inert Gas 10^5 N/M ²) (with stirring)	Same
Time at Dwell (molten)	2-4 min.	1-5 min.
Cooling Rate		
High	100°C/sec	Same
Cooling Method	Radiation	Same
Time to Cool to Recovery Temp	2-4 min.	0.1-10 min.
Heating Power	3-4 KW	45-50 KW
Input Power (71% effic)	4-6 KW	60-70 KW
Product Recovery	Mechanical	Mechanical
Total Process time	5-10 min.	15-50 min.
Vehicle Acceleration during	10^{-4} G	10^{-4} G

Figure II-9. Tungsten Process Baseline

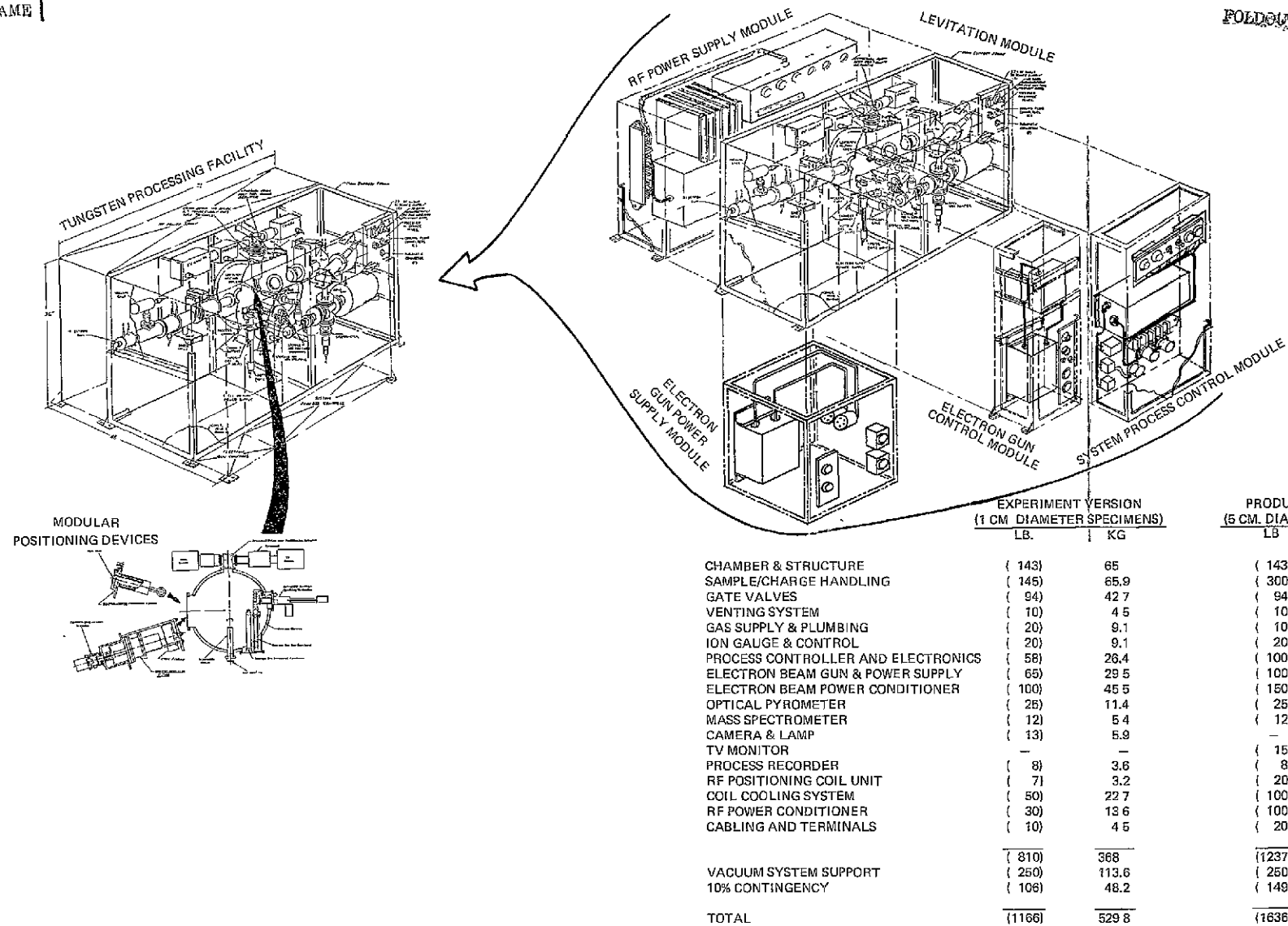


Figure II-10. Modular Tungsten Processing Facility

EQUIPMENT NAME HIGH VACUUM PUMP (L 45 E, SUPPLEMENTED)		DATE 12/30						
1 AVAILABILITY STATUS								
☐ NEW, REQUIRES YEARS TO DEVELOP ☐ MODIFICATION OF AVAILABLE EQUIP. COMPANY ☒ PRESENTLY AVAILABLE, COMPANY CVC, VEECO, NRC ☐ SPACE QUALIFIED, PROGRAM ☐ OTHER								
2 EXPERIMENTS ACCOMMODATED. (EXPERIMENT NAME OR TYPE)								
<table border="0"> <tr> <td>• Crystal Growth</td> <td rowspan="2">}</td> <td rowspan="2">{</td> <td>• Vacuum Purification</td> </tr> <tr> <td>• Glass Formation</td> <td>• Supercooling and Nucleation</td> </tr> </table>			• Crystal Growth	}	{	• Vacuum Purification	• Glass Formation	• Supercooling and Nucleation
• Crystal Growth	}	{	• Vacuum Purification					
• Glass Formation			• Supercooling and Nucleation					
3 DESCRIPTION OF EQUIPMENT OPERATION (MAJOR FUNCTIONS)								
Maintain vacuum of 10^{-6} torr or better. Types applicable to space applications are (1) Ion pumps, titanium sublimation pumps; getter-ion pumps, film-getterer pumps, cryopumps								
4 EQUIPMENT PHYSICAL DESCRIPTION (SKETCH, DIMENSIONS, VOLUME)								
• No. Req'd - 2 TYPICAL TRIODE GETTER-ION PUMP (About 1M long by .3M wide cylindrical), 25 KG								
5. EQUIPMENT PERFORMANCE PARAMETERS (E G , FLOW RATE, ENERGY OUTPUT, MAX TEMP , ETC)								
1) Capacity at 10^{-6} torr about 500-1000 liter/sec. at pump throat. 2) Throughput should be about 10^{-3} torr-liter/sec. at 10^{-6} torr.								

Figure II-11. Ground-Based Equipment Reviewed for Space Pressing Tungsten

EQUIPMENT NAME HIGH VACUUM PUMP (4SE SUPPLEMENTED)		DATE 12/30
6. INSTRUMENTATION (E.G., THERMOCOUPLES, GAUGES, ETC, LOCAL & REMOTE)		
Ion gauge to measure pressure at throat of pump. Ammeter to measure ion current in microamps, milliamps, amps. Solenoid to drive air valve.		
7. SUPPORT SERVICES REQUIRED (E G, POWER, GASSES, VACUUM, COOLANT, OPERATOR ATTENTION)		
• POWER	$\angle$ PEAK _____ sustained _____	1000 WATTS 50 WATTS
• DATA REQ'D	_____ 40 BITS PER SECOND	
8 EXTERNAL ENVIRONMENT REQUIRED (E G, ATMOSPHERE, VIBRATION LEVEL, ETC)		
Valve cannot be opened to atmosphere. To start pump, vacuum chamber must be pumped down to 0.5 micron (5×10^{-4} torr) Pump magnets cannot be heated.		
9 EXTERNAL ENVIRONMENT PRODUCED (E G., EMI, HEAT, CONTAMINATION, ETC)		
Heat. If ion pump heats up too much, pump will stall. Magnetic field pole pieces are 10 kilogauss.		
10. SAFETY CONSIDERATIONS (EQUIPMENT, OPERATORS, ETC)		
Interlock to shut off pump and <u>close</u> pump valve, if pump stalls or pressure rises too high. High voltage over 1K.V. Heat, breakdown by arcing. Magnetic pole piece can exert damaging force if brought close to ferromagnetic material.		
11. WASTES & PRODUCTS PRODUCED		
Heat, ~1KW peak.		

Figure II-11. Ground-Based Equipment Reviewed for Space Pressing Tungsten (Cont'd)

EQUIPMENT NAME High Vacuum Pump (L45E, Supplemented)	DATE 12/30
12 DATA INPUT/OUTPUT REQUIREMENTS (AS EXTRACTED FROM ITEM 13) • Data req'd - 40 bits per second Ion current Pressure at pump throat Voltage between anode and cathode (supply voltage)	
13 FUNCTIONAL FLOW DIAGRAM (INCLUDE & NOTE AUTOMATED FUNCTIONS, DATA FLOW, CONTROL RANGES & LIMITS, ETC) <pre> graph TD Switch[SWITCH ON/OFF] --> Supply[SUPPLY PUMP POWER] Supply --> MeasureV[MEASURE OUTPUT VOLTAGE] Supply --> Pump[PUMP] Pump --> MeasureTemp[MEASURE PUMP TEMP] Pump --> MeasureI[MEASURE ION CURRENT] Pump --> Valve[PUMP VALVE] Valve --> Interlock[INTER-LOCK] Interlock --> IonGauge[ION GAUGE] IonGauge --> Interlock Interlock --> Switch Valve --> Connect[CONNECT VACUUM CHAMBER TO PUMP] Connect --> Maintain[MAINTAIN 10⁻⁶ TORR OR BETTER IN VACUUM CHAMBER] </pre>	

Figure II-11. Ground-Based Equipment Reviewed for Space Pressing Tungsten (Cont'd)

EQUIPMENT NAME IR PYROMETER (L20 E) From TRW Study NAS 28938		DATE 12/19/74
1 AVAILABILITY STATUS		
☐ NEW, REQUIRES YEARS TO DEVELOP ☐ MODIFICATION OF AVAILABLE EQUIP. COMPANY ☒ PRESENTLY AVAILABLE, COMPANY IRCON OR HY HACKER ASSOCIATES ☐ SPACE QUALIFIED, PROGRAM ☐ OTHER		
2 EXPERIMENTS ACCOMMODATED (EXPERIMENT NAME OR TYPE)		
Crystal growth Glass preparation METALLURGICAL PROCESSES		
3 DESCRIPTION OF EQUIPMENT OPERATION (MAJOR FUNCTIONS)		
MEASURE, RECORD, PROVIDE SIGNAL DENOTING, TEMPERATURE OF SPECIMEN WITHOUT PHYSICALLY CONTACTING IT. (OPTICALLY SENSES RADIANT ENERGY EMITTED FROM SPECIMEN SURFACE.) OPTICAL PATH TO SPECIMEN MUST BE FREE OF BOTH COLD OR HOT OBSTRUCTIONS THAT ARE NOT OPTICALLY THIN AT MEASURING WAVELENGTHS.		
4 EQUIPMENT PHYSICAL DESCRIPTION (SKETCH, DIMENSIONS, VOLUME)		
.3 M by .3M by .3M --- .027M ³ 9.1KG. SENSOR HEAD MINIMUM DISTANCE FROM SPECIMEN - 7.6 CM.		
5 EQUIPMENT PERFORMANCE PARAMETERS (E G., FLOW RATE, ENERGY OUTPUT, MAX TEMP, ETC)		
TEMPERATURE RANGE - 40 to 3000 °C		

Figure II-12. Equipment - IR Pyrometer (L20 E) from TRW Study NAS 28938

EQUIPMENT NAME IR PYROMETER (L20 E)	DATE 12/19/74
6. INSTRUMENTATION: (E.G., THERMOCOUPLES, GAUGES, ETC, LOCAL & REMOTE) GAUGES INTEGRAL WITH PYROMETER.	
7. SUPPORT SERVICES REQUIRED (E.G., POWER, GASSES, VACUUM, COOLANT, OPERATOR ATTENTION) POWER - 20 WATTS (115 V - 60 Hz) DATA LINK (HARDWIRE) WITH PROCESS CONTROLLER, RECORDER THERMAL CONTROL TO MAINTAIN SENSING HEAD AMBIENT TEMPERATURE AT -32 to 94 °C	
8 EXTERNAL ENVIRONMENT REQUIRED (E.G., ATMOSPHERE, VIBRATION LEVEL, ETC) NONE	
9 EXTERNAL ENVIRONMENT PRODUCED (E.G., EMI, HEAT, CONTAMINATION, ETC) NONE	
10 SAFETY CONSIDERATIONS (EQUIPMENT, OPERATORS, ETC) SENSOR WINDOW(S) COMPATIBLE WITH SPECIMEN TEMPERATURE ELECTRICAL FUSING, POTTING AGAINST ELECTRICAL HAZARD SHUTTLE USE REQUIRES 3 G LOAD COMPATIBILITY MOUNTING MUST WITHSTAND 9G	
11 WASTES & PRODUCTS PRODUCED NONE	

Figure II-12. Equipment - IR Pyrometer (L20 E) from TRW
Study NAS 28938 (Cont'd.)

EQUIPMENT NAME IR PYROMETER (L20 E)	DATE 12/19/75
12. DATA INPUT/OUTPUT REQUIREMENTS (AS EXTRACTED FROM ITEM 13) 0 - 100 mV DC OUTPUT (100 OHM SOURCE) OR 0 - 100 V DC 2000 BPS	
13 FUNCTIONAL FLOW DIAGRAM (INCLUDE & NOTE AUTOMATED FUNCTIONS, DATA FLOW, CONTROL RANGES & LIMITS, ETC) <pre> graph LR SPECIMEN[SPECIMEN] -- RADIANT --> SENSING[SENSING] SPECIMEN -- ENERGY --> SENSING SPECIMEN -- ELECTRICAL --> SENSING SENSING -- "ELECTRICAL SIGNAL" --> AMPLIFICATION[AMPLIFICATION] AMPLIFICATION -- "AMPLIFIED SIGNAL" --> AND_OR((AND/ OR)) AND_OR -- "TO PROCESS CONTROL" --> PC[] AND_OR -- "TO DISPLAY" --> DIS[] AND_OR -- "TO RECORDING" --> REC[] </pre>	

Figure II-12. Equipment -IR Pyrometer (L20 E) from TRW
Study NAS 28938 (Cont'd.)

EQUIPMENT NAME MECHANICAL MANIPULATOR (INITIAL IDENTIFICATION)		DATE 4/9/75
1 AVAILABILITY STATUS		
☒ NEW, REQUIRES YEARS TO DEVELOP ☐ MODIFICATION OF AVAILABLE EQUIP, COMPANY ☐ PRESENTLY AVAILABLE, COMPANY ☐ SPACE QUALIFIED, PROGRAM ☐ OTHER		
2 EXPERIMENTS ACCOMMODATED (EXPERIMENT NAME OR TYPE)		
• Containerless processing of tungsten and transparent metal oxide glasses.		
3 DESCRIPTION OF EQUIPMENT OPERATION (MAJOR FUNCTIONS)		
(1) Insert raw specimen into chamber and into coil system. (2) Retrieve processed specimen from coil system and store it.		
4 EQUIPMENT PHYSICAL DESCRIPTION (SKETCH, DIMENSIONS, VOLUME)		
5 EQUIPMENT PERFORMANCE PARAMETERS (E.G., FLOW RATE, ENERGY OUTPUT, MAX TEMP, ETC)		
(1) Insert specimens into coil system at precise position (± 1 cm., all coordinates). (2) Retrieve specimens at prescribed temperatures (300° to 2000° C) without contamination.		

Figure II-13. Equipment - Mechanical Manipulator (Initial Identification)

EQUIPMENT NAME MECHANICAL MANIPULATOR (INITIAL IDENTIFICATION)	DATE 4/9/75
6. INSTRUMENTATION: (E.G., THERMOCOUPLES, GAUGES, ETC, LOCAL & REMOTE) Optical viewing (optional)	
7 SUPPORT SERVICES REQUIRED (E G , POWER, GASSES, VACUUM, COOLANT, OPERATOR ATTENTION) Inert Gas cooling, (optional)	
8 EXTERNAL ENVIRONMENT REQUIRED (E G., ATMOSPHERE, VIBRATION LEVEL, ETC) N/A	
9 EXTERNAL ENVIRONMENT PRODUCED (E G , EMI, HEAT, CONTAMINATION, ETC) N/A	
10 SAFETY CONSIDERATIONS. (EQUIPMENT, OPERATORS, ETC) Thermal and/or Mechanical Overload (Requires caution and warning interface, and (optional automatic cutout).	
11 WASTES & PRODUCTS PRODUCED N/A	

Figure II-13. Equipment - Mechanical Manipulator (Initial Identification) (Cont'd.)

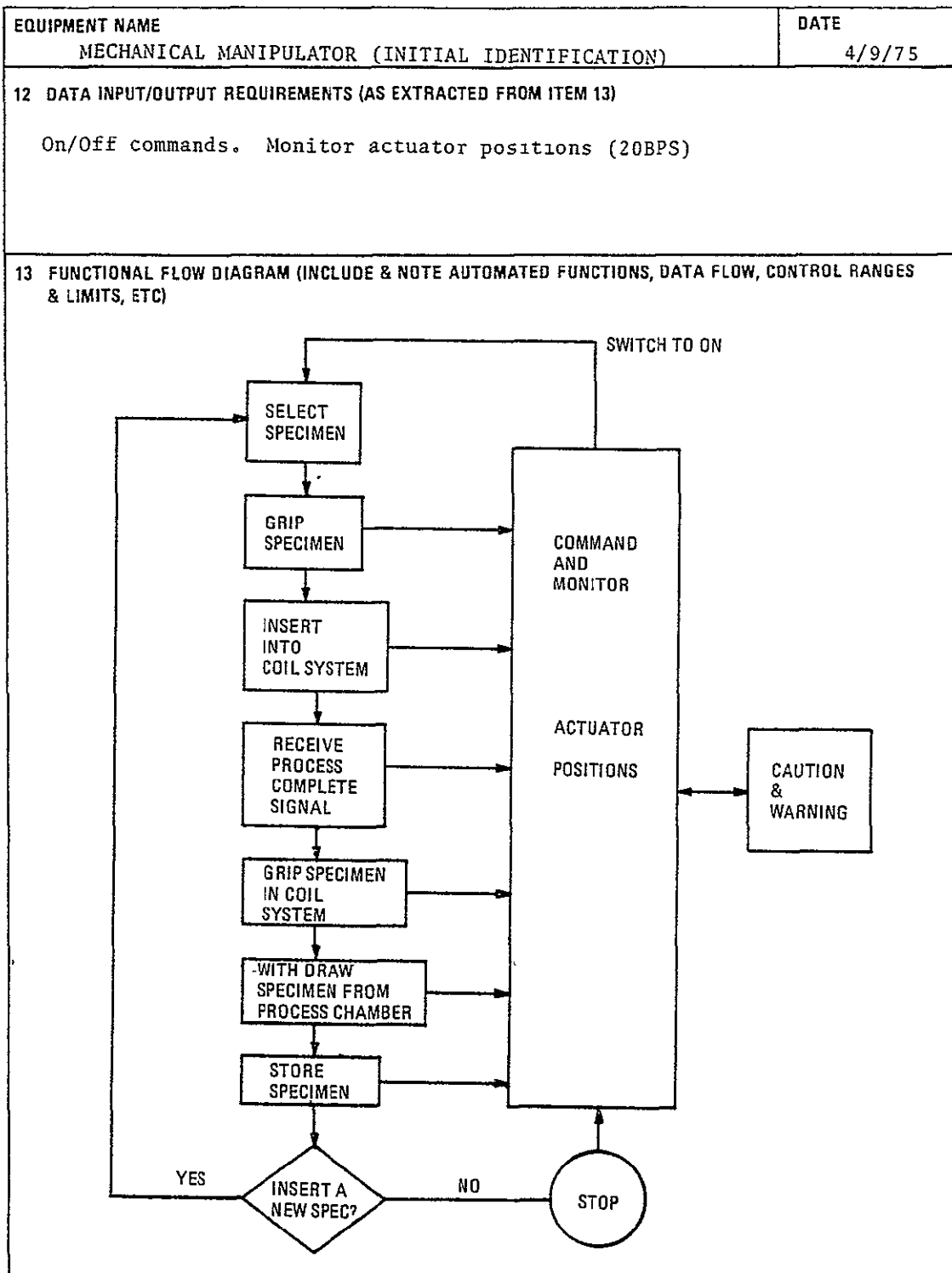


Figure II-13. Equipment - Mechanical Manipulator (Initial Identification) (Cont'd.)

	Development Required	Quantity Required Initial (Ground)	Quantity Required Prototype	Quantity Required Pilot (Space)	Quantity Required Production (Space)
Electron Beam Gun & Power Supply	Yes	1	1	1	2
EB Gun Controls	No	1	1	1	2
Optical Pyrometer	Design Optics	1	1	1	2
Sample Temp, Meas. & Control	No	1	1	1	2
Inert Gas Supply & Control	No	1	1	1	2
Positioning Device Power Supply & Control	Yes	1	1	1	2
Sample Cooling System & Control	Yes	1	1	1	2
Chamber Temp, Meas. & Control	Yes	1	1	1	2
Chamber Overtemp. Sensor & Cutoff	No	1	1	1	2
Vacuum Gage & Control	No	1	1	1	2
Gas Evacuation System & Control	No	1	1	1	2
Vacuum Pump & Power Supply	No	1	1	1	2
Coil Water Cooling System & Control	Yes	1	1	1	2
Positioning & RF Heating Device	Yes	1	1	1	2
Sample Loading Feature	Yes	1	1	1	2
Sample Unloading/Receiving Feature	Yes	1	1	1	2
Furnace Chamber	Yes	1	1	1	2

Figure II-14. Development Equipment List For Tungsten Processing

Requirement	Equipment or Operations Need
Safety	
• Temperature	- 3400°C molten tungsten requires enclosure, fireproofing, possibly emergency quench.
• Electrical Power	- RF power supply and electron beam gun power supply are high power, require grounding, fusing, potting.
• Radiation Particulate	- Low energy electrons, soft X-Rays Controlled by enclosure. Nominal precautions required.
RF	- Positioning and heating coil EMI requires shielding, filters in power line.
Optical	- Molten tungsten brightness requires eye shields.
Wastes	
• Gaseous	- Provision to remove inert, CO, CO ₂ , O ₂ , N ₂ , Steam
• Liquid	- Provision to Remove H ₂ O, possibly
• Solid	- Accommodate or remove deposits of tungsten or oxide
• Heat	- Thermal control for 60 to 200 x 10 ⁶ joules (Production) 1 TO 3 x 10 ⁶ joules (experiment)

Figure II-15. Special Requirements for Processing Tungsten

to provide a preliminary shaping of the tungsten during space processing, to a desired non-spherical shape. Present plans are based on postponement of this option and to perform any shaping (e.g., to a frustrum target shape) in a ground facility using conventional methods. The R&D activity then will consist of defining and testing the ground shaping process. Equipment and facilities for tungsten shaping presently exist so that, primarily, an applications engineering effort is required. However, questions must be resolved as to the forming method, contamination, waste, re-usability of waste, etc. in order to determine product costs and economic feasibility. For example, forming of X-ray target rings from tungsten sheet incurs waste of greater than 50% which must be reusable to be economical.

II.2.7 PRODUCT FINISHING (WBS 7.0)

This Work Element relates to the finishing of the X-ray tube target, which is a disc of molybdenum (7.7 to 13 cm diameter) to which a thin ring (track) of tungsten has been bonded. The R&D effort must establish the ring thickness, bonding and final finishing requirements for the target, to establish a product of expected long life (1.5 times present capability). Also the facility, process and equipment requirements must be met for pilot/production operations. Other product selections would require additional development work. The technology, facilities and equipment for this process presently exist, so that this constitutes primarily an applications engineering effort.

II.3 DEVELOPMENT SCHEDULE

The major activities required for tungsten process development and their phasing are as follows:

	Year
1. Analysis and planning	1973 - 75
2. Laboratory Experiments	1974 - 75

3. Special Equipment Development	1975 - 80
4. Shuttle Testing	1980 - 82
5. Operational Demonstration (Pilot)	1982 - 85
6. Full Operational Production in Space	1985 & Beyond

The detailed development schedule is shown in Figure II-16.

Laboratory experiments in the 1975-1980 period are primarily aimed at acquiring basic information on fundamental processing steps; degassing, levitation, electron beam heating (as a supplement to electromagnetic heating), and combined processing effects.

Drop Tower tests could provide useful data as early as 1975, while Zero "G" aircraft and Sounding Rocket tests in 1975 and 1976 are programmed for key positioning system tests. Sounding Rocket tests form the backbone of testing the major process steps (positioning, degassing, melting and supercooling) in 1975 to 1978. The low cost aspect of such testing is very attractive to the User.

TASK	WBS	74	75	76	77	78	79	80	81	82	83	84	85
PROGRAM MANAGEMENT	1 0	△ DEV PLAN			△ LAB TEST		△ SR TEST				△ PROTO TEST		
SYSTEM ENGINEERING	2 0		△ SR REQTS			△ SL REQTS				△ PROD REQTS			
BUSINESS OPERATIONS	3 0		△ BUSINESS PLAN						△ NASA SERVICE ARRANGEMENT				△ FULL SCALE PRODUCTION
STARTING TUNGSTEN PROCESS	4 0								△ PRODUCTION ORG				
GROUND LAB TESTS	4 1 1 2												
EQUIPMENT DEVELOPMENT	4 1 2												
PILOT/PRODUCTION	4 2												△ FULL SCALE PRODUCTION
TUNGSTEN SPACE PROCESS	5 0												
GROUND LAB TESTS	5 1 1 2												
SOUNDING ROCKET TESTS	5 1 1 3		△ SR1	△ SR2	△ SR3	△ SR4	△ SR5	△ SR6	△ SR7				
SHUTTLE TESTS	5.1 1 4							△ SH1	△ SH2	△ SH3			
EQUIPMENT DEVELOPMENT	5 1 2												
PILOT/PRODUCTION	5 2												△ FULL SCALE PRODUCTION
TUNGSTEN PRODUCT SHAPING	6 0												
R&D	6 1												
PILOT/PRODUCTION	6 2												
TUNGSTEN PRODUCT FINISHING	7 0												
R&D	7 1												
PILOT/PRODUCTION	7 2												

Figure II-16. Tungsten Product/Process Development Schedule

SECTION III

RESOURCES PLANNING

As in the preceding section, which extracted the program activities, their key milestones and timing, from the documented Work Elements in order to provide Development Planning data, we also analyzed the Resource Requirements and Resource Costs documents to extract the Resource Planning data.

Based on these requirements and costs, we have delineated the planned allocation of development costs for the Tungsten program under study. For programmatic purposes, these allocations have been assembled under several combinations of categories: type of resource, WBS elements, timing, and for both Case A and Case B.

A summary of the estimated costs for Case A, broken down by major resource category, is shown in Figure III-1A for each major WBS Element and in Figure III-1B for lower level WBS elements. The \$8.5 million total program cost includes the cost of Sounding Rocket Motors and NASA service charges for Sounding Rocket, KC-135 and Shuttle flights in the R&D phase.

A time-phased statement of those same costs for Case A is given in Figure III-2A, with Figure III-2B broken down to the lower levels of WBS elements.

Case B costs for R&D (wherein the User does not bear the proof-of-process-feasibility costs) are shown in Figure III-3.

It is important to recognize that costs are, in some cases, only measures of resources such as personnel with key skills, facilities, special equipment, etc. A tabulation of such resources by WBS element is shown in Figure III-4.

WBS	Task	Labor Cost	Purch. Mat'ls Cost	Services Cost	Equip. Cost	Facilities Cost	Total Cost	Time Period
1.1	Program Management	100K	-	677K	-	-	777K	75-82
2.1	System Engineering	100K	-	607K	-	-	707K	75-82
3.1	Business Operations	-	-	-	-	-	-	75-82
4.1	Starting Tungsten Process	38K	2K	16K	3K	-	59K	75-76
5.1	Space Processing	569K	883K	4787K	518K	-	6757K	75-82
6.1	Product Shaping Process	6K	2K	40K	102K	-	150K	80
7.1	Product Finishing Process	80K	10K	-	10K	-	100K	78-82
TOTALS		893K	897K	6127K	633K		8550K	

Figure III-1A. Case A - Tungsten Target R&D Program Cost Summary (by Cost Element)

WBS	Task	Labor Cost ¹	Purch Mat'l's Cost	Service Cost ²	Equip Cost	Facilities Cost	Total Cost	Time Period
1.1	Program Management	100K	-	677K	-	-	777K	75-82
2.1	System Engineering	100K	-	607K	-	-	707K	75-82
3.1	Business Operations	-	-	-	-	-	-	-
4.1	Starting Tungsten Process	38K	2K	16K	3K	-	59K	75-76
4.1.1	Project Engineering	32K	1K	16K	-	-	49K	75-76
4.1.1.1	Project Supervision	4K	-	-	-	-	4K	75-76
4.1.1.2	Ground Lab Studies	28K	1K	16K	-	-	45K	75-76
4.1.2	Equipment Dev	6K	1K	-	3K	-	10K	75-82
5.1	Space Processing	569K	883K	4787K	518K	-	6757K	75-82
5.1.1	Project Engineering	569K	883K	4787K	518K	-	6757K	75-82
5.1.1.1	Project Supervision	-	-	614K	-	-	614K	75-82
5.1.1.2	Ground Lab Studies	62K	13K	87K	8K	-	170K	75
5.1.1.2.1	Levitation	22K	5K	30K	3K	-	60K	75
5.1.1.2.2	Electron Beam Heating	12K	2K	10K	1K	-	25K	75
5.1.1.2.3	Vacuum Degas w/Levitation	12K	2K	10K	1K	-	25K	75
5.1.1.2.4	Lev. Heat, Melt, 1-G	16K	4K	37K	3K	-	60K	75
5.1.1.3	Sounding Rocket Tests	12K	780K	1008K	-	-	1800K	76-79
5.1.1.3.1	Limited Duration Position Tests	4K	312K	384K	-	-	700K	76-78
5.1.1.3.2	Limited Duration Heat, Degas	4K	156K	340K	-	-	500K	76-78
5.1.1.3.3	Limited Duration Melt, Cool	4K	312K	284K	-	-	600K	77-79
5.1.1.4	Shuttle Tests	495K	90K	3078K	510K	-	4173K	79-82
5.1.1.4.1	Proto Des. & Test	300K	75K	1721K	300K	-	2396K	78-81
5.1.1.4.2	Proof Test	150K	10K	1357K	210K	-	1727K	81-82
5.1.1.4.3	Product Evaluation	45K	5K	-	-	-	50K	81-82
5.1.2	Equipment Dev.	-	-	-	-	-	-	76-80
6.1	Product Shaping	6K	2K	40K	102K	-	150K	80
7.1	Product Finishing	80K	10K	-	10K	-	100K	78-82
	Totals	893K	897K	6127K	633K	-	8550K	
1. Labor of Commercial Sponsor								
2. Cost of Systems Contractor & Other Services								

Figure III-1B. Case A - Tungsten Development Program Cost Summary

WBS	Task	Total Cost	75	76	77	78	79	80	81	82
1.1	Program Management	777K	24K	40K	97K	75K	14K	181K	161K	185K
2.1	System Engineering	707K	22K	36K	88K	68K	13K	165K	147K	168K
3.1	Business Operations	-	-	-	-	-	-	-	-	-
4.1	Starting Tungsten Process	59K	30K	29K	-	-	-	-	-	-
5.1	Space Process	6757K	187K	330K	880K	660K	110K	1572K	1516K	1502K
6.1	Product Shaping	150K	-	-	-	-	-	150K	-	-
7.1	Product Finishing	100K	-	-	-	20K	20K	20K	20K	20K
	Totals	8550K	263K	435K	1065K	823K	157K	2088K	1844K	1875K

Figure III-2A. Case A - Tungsten Target R&D Program Summary (By Year)

WBS	Task	Total Cost	75	76	77	78	79	80	81	82
1.1	Program Management	777K	24K	40K	97K	75K	14K	181K	161K	185K
2.1	System Engineering	707K	22K	36K	88K	68K	13K	165K	147K	168K
3.1	Business Operations	-	-	-	-	-	-	-	-	-
4.1	Starting Tungsten Process	59K	30K	29K	-	-	-	-	-	-
4.1.1	Project Engineering	49K	25K	24K	-	-	-	-	-	-
4.1.1.1	Project Supervision	4K	2K	2K	-	-	-	-	-	-
4.1.1.2	Ground Lab Studies	45K	23K	22K	-	-	-	-	-	-
4.1.2	Equipment Development	10K	5K	5K	-	-	-	-	-	-
5.1	Space Processing	6757K	187K	330K	880K	660K	110K	1572K	1516K	1502K
5.1.1	Project Engineering	6757K	187K	330K	880K	660K	110K	1572K	1516K	1502K
5.1.1.1	Project Supervision	614K	17K	30K	80K	60K	10K	136K	131K	150K
5.1.1.2	Ground Lab Studies	170K	170K	-	-	-	-	-	-	-
5.1.1.2.1	Levitation	60K	60K	-	-	-	-	-	-	-
5.1.1.2.2	Electron Beam Heating	25K	25K	-	-	-	-	-	-	-
5.1.1.2.3	Vacuum Degas w/Levitation	25K	25K	-	-	-	-	-	-	-
5.1.1.2.4	Levitation, Heat, Melt, 1-G	60K	60K	-	-	-	-	-	-	-
5.1.1.3	Sounding Rocket Tests	1800K	-	300K	800K	600K	100K	-	-	-
5.1.1.3.1	Limited Duration Position Tests	700K	-	200K	300K	200K	-	-	-	-
5.1.1.3.2	Limited Duration Heat, Degas	500K	-	100K	300K	100K	-	-	-	-
5.1.1.3.3	Limited Duration Melt, Cool	600K	-	-	200K	300K	100K	-	-	-
5.1.1.4	Shuttle Tests	4173K	-	-	-	-	-	1436K	1385K	1352K
5.1.1.4.1	Proto Design & Test	2396K	-	-	-	-	-	1436K	960K	-
5.1.1.4.2	Proof Test	1727K	-	-	-	-	-	-	400K	1327K
5.1.1.4.3	Product Evaluation	50K	-	-	-	-	-	-	25K	25K
5.1.2	Equipment Development	-	-	-	-	-	-	-	-	-
6.1	Product Shaping	150K	-	-	-	-	-	150K	-	-
7.1	Product Finishing	100K	-	-	-	20K	20K	20K	20K	20K
	Totals	8550K	263K	435K	1065K	823K	157K	2088K	1844K	1875K

Figure III-2B. Case A - Tungsten Target R&D Program (By Year)

WBS	Task	Total	75	76	77	78	79	80	81	82
1.1	Program Management	398K	-	-	-	2K	2K	48K	161K	185K
2.1	System Engineering	362K	-	-	-	2K	2K	43K	147K	168K
3.1	Business Operations	-	-	-	-	-	-	-	-	-
4.1	Starting Tungsten Process	-	-	-	-	-	-	-	-	-
4.1.1	Project Engineering	-	-	-	-	-	-	-	-	-
4.1.1.1	Project Supervision	-	-	-	-	-	-	-	-	-
4.1.1.2	Ground Lab Studies	-	-	-	-	-	-	-	-	-
4.1.2	Equipment Development	-	-	-	-	-	-	-	-	-
5.1	Space Processing	3280K	-	-	-	-	-	262K	1516K	1520K
5.1.1	Project Engineering	3280K	-	-	-	-	-	262K	1516K	1502K
5.1.1.1	Project Supervision	305K	-	-	-	-	-	24K	131K	150K
5.1.1.2	Ground Lab Studies	-	-	-	-	-	-	-	-	-
5.1.1.2.1	Levitation	-	-	-	-	-	-	-	-	-
5.1.1.2.2	Electron Beam Heating	-	-	-	-	-	-	-	-	-
5.1.1.2.3	Vac Degas w/Levitation	-	-	-	-	-	-	-	-	-
5.1.1.2.4	Levt. Heat Melt, 1-G	-	-	-	-	-	-	-	-	-
5.1.1.3	Sounding Rocket Tests	-	-	-	-	-	-	-	-	-
5.1.1.3.1	Limited Duration Positioning	-	-	-	-	-	-	-	-	-
5.1.1.3.2	Limited Duration Heat Degas	-	-	-	-	-	-	-	-	-
5.1.1.3.3	Limited Duration Melt, Cool	-	-	-	-	-	-	-	-	-
5.1.1.4	Shuttle Tests	2975K	-	-	-	-	-	238K	1385K	1352K
5.1.1.4.1	Proto Design & Test	1198K	-	-	-	-	-	238K	960K	-
5.1.1.4.2	Proof Test	1727K	-	-	-	-	-	-	400K	1327K
5.1.1.4.3	Product Evaluation	50K	-	-	-	-	-	-	25K	25K
5.1.2	Equipment Development	-	-	-	-	-	-	-	-	-
6.1	Product Shaping	150K	-	-	-	-	-	150K	-	-
7.1	Product Finishing	100K	-	-	-	20K	20K	20K	20K	20K
	Totals	4290K	-	-	-	24K	24K	523K	1844K	1875K

Figure III-3. Case B - Tungsten Target User R&D Program
(excludes all tasks associated with establishing process feasibility)

WBS	Task	Period (Yrs)	Skills	Materials	Services	Equipment	Facilities
1 1	Program Management	75 84	Conventional	-	-	-	Conventional
2 1	System Engineering	75 82	Conventional	-	-	-	Conventional
3 1	Business Operations	75 85 & Beyond	Conventional	-	Market Research	-	Conventional
4 1 4 1 1	Starting Tungsten Process Process Development	75 82 75 80	Tungsten Metallurgists Adv Process Tech's	Wrought Tungsten, Pressed and Sintered Tungsten	Adv Metals Testing Emission Spectro photometry Tests Conductometric Tests Vacuum Fusion Tests Degassing Tests	Tungsten Proc Equipment Metallographic Microscope X ray Diffractometer Vacuum Degassing Encapsulation Equipment Vacuum Induction Furnace Electron Probe Microanalyzer	Metal Processing Metallographic Lab Chem Composition Lab Physical Properties Lab
4 1 2	Equipment Development	76 80	Conventional	-	-	-	-
5 1 5 1 1 5 1 1 2	Tungsten Space Processing Process Development Ground Lab Tests	75 84 75 82 75	Tungsten Metallurgists Spectrometrists Adv Process Tech's	Commercial & High Purity Tungsten Wrought Tungsten Pressed and Sintered Tungsten	Levitation & Melt Laboratory NASA Sounding Rocket Services NASA Shuttle/Space Lab Services	Levitation & Melt Equipment RF Positioning Electron Beam Heating Heating Mass Spectrometer Gas Sampling X ray Stress Analysis Electron Microscope	Metal Processing & Test Lab Vacuum Processing Metallurgical Lab Machine Shop X ray Shielding
5 1 1 3	Sounding Rocket Tests	75 79	Tungsten Metallurgists Advanced Process Tech's	Commercial & High Purity Tungsten	KC 135/Drop Tower Services NASA Launch, Flight & Rec Services Sounding Rockets (Black Brant)	Levitation & Melt Equipment Sounding Rockets	NASA Launch Facilities Pre Flight and Post Flight Test Lab (Materials Analysis)
5 1 1 4	Shuttle Tests	79 84	Metallurgists/Tech's	Commercial & High Purity Tungsten Tungsten Billets of Various Purities	Shuttle/Spacelab Transport and Support Services	X ray Test Chamber and Instrumentation Auto Life Test Equipment	X ray Target and Tube Metallurgical Lab
5 1 2	Equipment Development	75 85+	Space Equipment Design	Commercial & High Purity Tungsten	-	Conventional	Conventional
6 1 6 1 1 6 1 1 2	Tungsten Product Shaping Process Development Ground Lab Tests	75 77	Metallurgists Equipment Applications Engineers	Space Processed Tungsten Spheres	Research Lab for Analysis and Materials Characterization	Conventional (with mod)	Research Lab Tungsten Processing Machine Shop

Figure III-4. Tungsten Resource Summary

SECTION IV

CASH FLOW ANALYSIS

The data inputs and parameter values used in the baseline Case A (user bears full R&D costs), cash flow analysis are shown in Figure IV-1. The financial forecast for this case for the period 1975-1992 is presented in Figures IV-2A and 2-B. A total market demand of 80,300 target segments is projected in 1980, growing to 161,600 by 1992. The market share builds up to about 25% by 1992. The unit price per target segment remains at \$442 for all years, owing to the lack of a basis for profiling this value.

The same baseline information applies to Case B, Figure IV-3, except that the user-funded research and development program to establish a production capability after demonstration of process feasibility by NASA is estimated at \$4.3 million. The detailed cash flow of Case B is shown in Figure IV-4. Finally, for Case C we have explored some of the potential "What if's" that could be conceived as alternative scenarios. As shown in Figure IV-5, we have increased the market share to 50% and lowered the unit cost. Such changes are not outlandish. If the product achieves its full potential, users will save significant amounts of money, thus opening the door to new markets. Also the advent of solar concentrators for high temperature material melting could provide a significant cost saving.

Various sets of assumptions in terms of throughput and approach were tried in establishing the baseline process which could produce a target segment at an acceptable unit price. Financial analysis was based on estimation of the following 6 items over the period 1975-1992.

Total Market - world demand for x-ray tubes (and therefore the demand for x-ray tube target segments) based on current growth rates. The forecast lumps the demand for 3, 4, and 5-inch tubes/targets into one figure for each year.

Market Share - per cent of total market to be satisfied by the producer, based on a gradual stabilization at 25% of the total market, (Cases A and B); 50% for Case C.

Unit Price - based on the estimated price that an x-ray tube manufacturer could afford to pay, and be able to profitably incorporate the improved target in a premium-price x-ray tube.

Unit Manufacturing Cost - based on an itemized cost breakdown of the starting tungsten preparation and in-space refinement processes, including space service charges.

Research and Development Cost - based on an estimate of the ground lab and space shuttle experiments required to go into production after NASA has demonstrated feasibility of the space process. (Case B).

Annual Plant and Equipment - based on equipment needed to establish ground and space production capabilities, assuming use of existing buildings. A ten-year straight line depreciation was used for all items.

A simplified financial forecast routine was then used to determine the following business venture performance measures:

Per Cent Return on Investment (ROI)

This is calculated as annual net profit (after taxes and before payment of dividends) divided by net annual investment. The significance of the ROI measure is that it indicates the yield to the business after all costs are deducted. It can be compared on an annual basis to the return which might be obtained from an alternate investment of the same funds, including the option of putting the money in a bank savings account. The Case B ROI obtained is 41% in 1992, which is a good indicator, relative to a nominal expectation of 15-20%.

Per Cent Net Income to Sales (NI/S)

This is calculated as annual net profit (after taxes and before dividends) divided by annual sales. The significance of the NI/S measure is that it indicates the yield relative to the amount of business (sales) that is being conducted, for comparison with the yield that this type of business normally expects to achieve. The NI/S figure (Case B) for 1992 is 13%, which is good compared to the metal products industry NI/S of 3.6% (in 1972).

Cumulative Cash Flow

This is the summation of the annual amounts of money which must be put into (or can be taken out of) the business over the forecast period. Annual cash flows are determined as the annual net income after taxes less the annual net change in investment. The summation of the annual cash flows over time gives the cumulative cash flow. In general, the sooner that a business can generate positive cash flow (excess cash), the more attractive the venture. In the years when annual cash flow is positive, the business is generating more cash than is needed to operate the business. At the time when cumulative cash flow turns positive, the business will have paid back all of the money put into the business up to that point. The cumulative cash flow for the tungsten venture (Case B) turns positive in 1989, 12 years after first expenditures, and 10 years after first major expenditures. This is a poor indicator, since a nominal expectation would be to achieve a positive cumulative cash flow in, say 5 years, unless the long term benefits were outstanding and warranted the higher risk. No attempt was made in the study to rephase the development program for improvement of the breakeven period.

Present Value

This is a measure of the worth today of funds expected to be paid out or received in the future based on a chosen discount rate. The present value of the business is calculated by discounting the annual cash flow at a discount rate of 10 per cent. The net annual investment in the last year of the forecast period, which can be taken as a measure of the liquidation value of the business, was included in the calculation. The Case B present value is \$1.7 million (positive), which is a good indicator.

The significance of the present value measure is that at zero present value, a businessman is indifferent (theoretically) as to whether he puts his money in the bank at interest (at the assumed discount rate), or into the business (disregarding business risk). For a positive present value, he would rather put his money into the business.

Constants were established for calculation of costs other than those inputted, as shown in Figures IV-1, -3, -5. Space charges based on the BUS Phase III model were included in the R&D and production costs. The relatively bulky, heavy, high-energy-consumption characteristics of the tungsten space facility make it highly sensitive to the charges made for space services.

INPUTS:	75	76	77	78	79	80	81	82	83	84
TOTAL MARKET (UNITS)	0.	0.	0.	0.	0.	80400.	85100.	90200.	95600.	101000.
MARKET SHARE (PCT)	0.	0.	0.	0.	0.	0.	0.	2.	4.	8.
UNIT PRICE	0.	0.	0.	0.	0.	0.	0.	442.	442.	442.
UNIT MANUFACTURING COST	.00	.00	.00	.00	.00	.00	.00	222.00	222.00	222.00
R AND D EXPENSE	263000.	435000.	1065000.	823000.	157000.	2088000.	1844000.	1875000.	0.	0.
ANNUAL PLANT AND EQUIP.	0.	0.	0.	0.	0.	0.	1290000.	0.	0.	0.
INPUTS:	85	86	87	88	89	90	91	92	93	94
TOTAL MARKET (UNITS)	107500.	114000.	121000.	128000.	135600.	143800.	152400.	161600.	0.	0.
MARKET SHARE (PCT)	15.	28.	33.	31.	29.	28.	26.	25.	0.	0.
UNIT PRICE	442.	442.	442.	442.	442.	442.	442.	442.	0.	0.
UNIT MANUFACTURING COST	222.00	222.00	222.00	222.00	222.00	222.00	222.00	222.00	.00	.00
R AND D EXPENSE	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
ANNUAL PLANT AND EQUIP.	0.	500000.	0.	0.	0.	0.	790000.	0.	0.	0.
PARAMETRIC PERCENTAGES:										
PARAMETER	IDENTIFIER	VALUE	PARAMETER	IDENTIFIER	VALUE					
INTEREST RATE	P11	10.00	UNITS MANUFACTURED PCT.	P21	120.00					
AVERAGE INVENTORY PCT.	P23	20.00	ENGINEERING EXPENSE PCT.	P26	5.00					
SELLING EXPENSE PCT.	P27	5.00	ADMINISTRATION EXPENSE PCT	P28	10.00					
RECEIVABLES PCT.	P31	20.00	DEPRECIATION PERIOD(YRS)	P35	10.00					
OTHER INVESTMENT PCT.	P38	5.00								
PERCENTAGE OF BASELINE USED										
INPUTS	IDENTIFIER	PCT	ADD/SUB FROM BASELINE INPUTS	IDENTIFIER	VALUE					
TOTAL MARKET	x1	100		A1	0.					
MARKET SHARE	x2	100		A2	0.					
UNIT PRICE	x3	100		A3	.00					
UNIT MANUFACTURING COST	x4	100		A4	0.					
R AND D EXPENSE	x5	100		A5	0.					
ANNUAL PLANT AND EQUIP.	x6	100		A6	0.					

Figure IV-1. Tungsten Case A Input Values

	75	76	77	78	79	80	81	82	83	84
TOTAL MARKET (UNITS)	0.	0.	0.	0.	0.	80300.	85100.	90200.	95600.	101000.
MARKET SHARE (PCT)	.00	.00	.00	.00	.00	.00	.00	2.20	4.20	7.90
UNITS SOLD (UNITS)	0.	0.	0.	0.	0.	0.	0.	1984.	4015.	7979.
UNIT PRICE	0.	0.	0.	0.	0.	0.	0.	442.	442.	442.
SALES	0.	0.	0.	0.	0.	0.	0.	877105.	1774718.	3526718.
OPERATING EXPENSES	263000.	435000.	1065000.	823000.	157000.	2088000.	1973000.	2655796.	1447833.	2749782.
GROSS PROFITS	-263000.	-435000.	-1065000.	-823000.	-157000.	-2088000.	-1973000.	-1778691.	-326886.	-776936.
ANNUAL INVESTMENT	0.	0.	0.	0.	0.	0.	1161000.	1269295.	1383138.	1728129.
CUMULATIVE GROSS PROFITS	-263000.	-698000.	-1763000.	-2586000.	-2743000.	-4831000.	-6804000.	-8582691.	-8255805.	-7478870.
BASE FOR INTEREST EXP.	263000.	698000.	1763000.	2586000.	2743000.	4831000.	7965000.	9851986.	9638943.	9206999.
INTEREST EXPENSE	26300.	69800.	176300.	258600.	274300.	483100.	796500.	985199.	963894.	920700.
INCOME BEFORE TAXES	-289300.	-504800.	-1241300.	-1081600.	-431300.	-2571100.	-2769500.	-2763890.	-637008.	-143764.
TAXES	-138864.	-242304.	-595824.	-519168.	-207024.	-1234128.	-1329360.	-1326667.	-305764.	-69007.
NET INCOME AFTER TAXES	-150436.	-262496.	-645476.	-562432.	-224276.	-1336972.	-1440140.	-1437223.	-331244.	-74767.
NET CHANGE IN INVEST.	0.	0.	0.	0.	0.	0.	1161000.	108295.	113843.	344991.
ANNUAL CASH FLOW	-150436.	-262496.	-645476.	-562432.	-224276.	-1336972.	-2601140.	-1545517.	-445087.	-419749.
CUMULATIVE CASH FLOW	-150436.	-412932.	-1058408.	-1620840.	-1845116.	-3182088.	-5783228.	-7328745.	-7773833.	-8193581.
RETURN ON INVESTMENT(PCT)	.00	.00	.00	.00	.00	.00	-124.04	-113.23	-23.95	-4.33
NET INCOME TO SALES (PCT)	.00	.00	.00	.00	.00	.00	.00	-163.86	-18.66	-2.12

OPERATING EXPENSES

UNIT MANUFACTURING COST	.00	.00	.00	.00	.00	.00	.00	222.00	222.00	222.00
UNITS MANUFACTURED(UNITS)	0.	0.	0.	0.	0.	0.	0.	2381.	4818.	9675.
COST OF GOODS MFG.	0.	0.	0.	0.	0.	0.	0.	528644.	1069649.	2125606.
AVERAGE INVENTORY***	0.	0.	0.	0.	0.	0.	0.	105729.	213930.	425121.
R AND D EXPENSE	263000.	435000.	1065000.	823000.	157000.	2088000.	1844000.	1875000.	0.	0.
ENGINEERING EXPENSE	0.	0.	0.	0.	0.	0.	0.	26432.	53482.	106280.
SELLING EXPENSE	0.	0.	0.	0.	0.	0.	0.	43855.	88736.	176336.
ADMINISTRATION EXPENSES	0.	0.	0.	0.	0.	0.	0.	52864.	106965.	212561.
DEPRECIATION EXPENSES**	0.	0.	0.	0.	0.	0.	129000.	129000.	129000.	129000.
TOTAL OPERATING EXPENSES	263000.	435000.	1065000.	823000.	157000.	2088000.	1973000.	2655796.	1447833.	2749782.

INVESTMENT

RECEIVABLES (AVG)	0.	0.	0.	0.	0.	0.	0.	175421.	354944.	705344.
INVENTORIES (AVG)	0.	0.	0.	0.	0.	0.	0.	105729.	213930.	425121.
ANNUAL PLANT AND EQUIP.	0.	0.	0.	0.	0.	0.	1290000.	0.	0.	0.
CUMULATIVE PLANT + EQUIP.	0.	0.	0.	0.	0.	0.	1290000.	1290000.	1290000.	1290000.
ANNUAL DEPRECIATION	0.	0.	0.	0.	0.	0.	129000.	129000.	129000.	129000.
CUMULATIVE DEPRECIATION	0.	0.	0.	0.	0.	0.	129000.	258000.	387000.	516000.
NET PLANT + EQUIP.	0.	0.	0.	0.	0.	0.	1161000.	1032000.	903000.	774000.
OTHER INVESTMENT****	0.	0.	0.	0.	0.	0.	0.	43855.	88736.	176336.
NET ANNUAL INVESTMENT	0.	0.	0.	0.	0.	0.	1161000.	1269295.	1383138.	1728129.
PRESENT VALUE OF ANNUAL CASH FLOW			-1115500.							

* ASSUME TAX LOSS IS CREDITED AGAINST OTHER BUSINESS INCOME.

** THIS ITEM IS NORMALLY INCLUDED IN VARIOUS OVERHEAD ACCOUNTS.

*** INVENTORY DERIVATION IS HIGHLY SIMPLIFIED, BUT APPROXIMATES MORE COMPLEX METHODS

**** INCLUDES MISC. LIABILITIES SUCH AS ACCOUNTS PAYABLE, RESERVES, SUNDRY CREDITOR ITEMS

Figure IV-2A. Tungsten Case A Cash Flow Analysis

	85	86	87	88	89	90	91	92	93	94
TOTAL MARKET (UNITS)	107500.	114000.	121000.	128000.	135600.	143800.	152400.	161600.	0.	0.
MARKET SHARE (PCT)	14.90	28.10	33.00	31.30	29.50	27.80	26.20	24.80	0.00	0.00
UNITS SOLD (UNITS)	16017.	32034.	39930.	40064.	40000.	39976.	39929.	40077.	0.	0.
UNIT PRICE	442.	442.	442.	442.	442.	442.	442.	442.	0.	0.
SALES	7079735.	14159020.	17649060.	17708288.	17680854.	17669569.	17648530.	17713946.	0.	0.
OPERATING EXPENSES	5390108.	10700888.	13294408.	13338421.	13318057.	13309648.	13244014.	13292626.	0.	0.
GROSS PROFITS	1689627.	3458140.	4354652.	4369867.	4362827.	4359920.	4404516.	4421320.	0.	0.
ANNUAL INVESTMENT	2560373.	4796620.	5561829.	5398853.	5212439.	5030378.	5685686.	5574384.	0.	0.
CUMULATIVE GROSS PROFITS	-5789243.	-2331102.	2023550.	6393416.	10756249.	15116164.	19520680.	23942000.	0.	0.
BASE FOR INTEREST EXP.	8349615.	7127726.	3538280.	0.	0.	0.	0.	0.	0.	0.
INTEREST EXPENSE	634962.	712773.	353828.	0.	0.	0.	0.	0.	0.	0.
INCOME BEFORE TAXES	854665.	2745368.	4000824.	4369867.	4362827.	4359920.	4404516.	4421320.	0.	0.
TAXES	410239.	1317776.	1920396.	2097536.	2094157.	2092762.	2114168.	2122234.	0.	0.
NET INCOME AFTER TAXES	444426.	1427591.	2080429.	2272331.	2268670.	2267159.	2290348.	2299086.	0.	0.
NET CHANGE IN INVEST.	832244.	2236753.	765204.	-162976.	-186414.	-182061.	655308.	-111302.	0.	0.
ANNUAL CASH FLOW	-387818.	-808662.	1315225.	2435307.	2455084.	2449220.	1635040.	2410388.	0.	0.
CUMULATIVE CASH FLOW	-8581399.	-9390061.	-8074836.	-5639529.	-3184445.	-735225.	899815.	3310203.	0.	0.
RETURN ON INVESTMENT (PCT)	17.36	29.76	37.41	42.09	43.52	45.07	40.28	41.24	0.00	0.00
NET INCOME TO SALES (PCT)	6.28	10.08	11.79	12.83	12.83	12.83	12.98	12.98	0.00	0.00
O P E R A T I N G E X P E N S E										
UNIT MANUFACTURING COST	222.00	222.00	222.00	222.00	222.00	222.00	222.00	222.00	0.00	0.00
UNITS MANUFACTURED (UNITS)	19221.	38441.	47916.	48077.	48002.	47972.	47915.	48092.	0.	0.
COST OF GOODS MFG.	4267062.	8533858.	10637352.	10673050.	10656533.	10649713.	10637032.	10676460.	0.	0.
AVERAGE INVENTORY***	853412.	1706772.	2127470.	2134610.	2131307.	2129943.	2127406.	2135292.	0.	0.
R AND D EXPENSE	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
ENGINEERING EXPENSE	213353.	426693.	531808.	533652.	532827.	532486.	531852.	533823.	0.	0.
SELLING EXPENSE	353987.	707951.	882453.	885414.	884044.	883478.	882426.	885697.	0.	0.
ADMINISTRATION EXPENSES	426706.	853386.	1 63735.	1067305.	1065653.	1064971.	1063703.	1067646.	0.	0.
DEPRECIATION EXPENSES**	129000.	179000.	179000.	179000.	179000.	179000.	129000.	129000.	0.	0.
TOTAL OPERATING EXPENSES	5390108.	10700888.	13294408.	13338421.	13318057.	13309648.	13244014.	13292626.	0.	0.
I N V E S T M E N T										
RECEIVABLES (AVG)	1415947.	2831826.	3529812.	3541658.	3536177.	3533914.	3529706.	3542789.	0.	0.
INVENTORIES (AVG)	853412.	1706772.	2127470.	2134610.	2131307.	2129943.	2127406.	2135292.	0.	0.
ANNUAL PLANT AND EQUIP.	0.	500000.	0.	0.	0.	0.	790000.	0.	0.	0.
CUMULATIVE PLANT + EQUIP.	1290000.	1790000.	1790000.	1790000.	1790000.	1790000.	2580000.	2580000.	0.	0.
ANNUAL DEPRECIATION	129000.	179000.	179000.	179000.	179000.	179000.	129000.	129000.	0.	0.
CUMULATIVE DEPRECIATION	645000.	824000.	1003000.	1182000.	1361000.	1540000.	1669000.	1798000.	0.	0.
NET PLANT + EQUIP.	645000.	966000.	187000.	608000.	429000.	250000.	911000.	782000.	0.	0.
OTHER INVESTMENT****	353987.	707951.	882453.	885414.	884044.	883478.	882426.	885697.	0.	0.
NET ANNUAL INVESTMENT	2560373.	4796620.	5561829.	5398853.	5212439.	5030378.	5685686.	5574384.	0.	0.
PRESENT VALUE OF ANNUAL CASH FLOW			-1115500.							

* ASSUME TAX LOSS IS CREDITED AGAINST OTHER BUSINESS INCOME.

** THIS ITEM IS NORMALLY INCLUDED IN VARIOUS OVERHEAD ACCOUNTS.

*** INVENTORY DERIVATION IS HIGHLY SIMPLIFIED, BUT APPROXIMATES MORE COMPLEX METHODS

**** INCLUDES MISC. LIABILITIES SUCH AS ACCOUNTS PAYABLE, RESERVES, Sundry CREDITOR ITEMS

Figure IV-2B. Tungsten Case A Cash Flow Analysis

INPUTS:	75	76	77	78	79	80	81	82	83	84
TOTAL MARKET (UNITS)	0.	0.	0.	0.	0.	80100.	85100.	90200.	95600.	101000.
MARKET SHARE (PCT)	0.	0.	0.	0.	0.	0.	0.	2.	4.	8.
UNIT PRICE	0.	0.	0.	0.	0.	0.	0.	442.	442.	442.
UNIT MANUFACTURING COST	.00	.00	.00	.00	.00	.00	.00	222.00	222.00	222.00
R AND D EXPENSE	0.	0.	0.	24000.	24000.	523000.	184400.	1875000.	0.	0.
ANNUAL PLANT AND EQUIP.	0.	0.	0.	0.	0.	0.	1290000.	0.	0.	0.

INPUTS:	85	86	87	88	89	90	91	92	93	94
TOTAL MARKET (UNITS)	107500.	114000.	121000.	128000.	135600.	143800.	152400.	161600.	0.	0.
MARKET SHARE (PCT)	15.	28.	33.	31.	29.	28.	26.	25.	0.	0.
UNIT PRICE	442.	442.	442.	442.	442.	442.	442.	442.	0.	0.
UNIT MANUFACTURING COST	222.00	222.00	222.00	222.00	222.00	222.00	222.00	222.00	.00	.00
R AND D EXPENSE	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
ANNUAL PLANT AND EQUIP.	0.	500000.	0.	0.	0.	0.	790000.	0.	0.	0.

PARAMETRIC PERCENTAGES:

PARAMETER	IDENTIFIER	VALUE	PARAMETER	IDENTIFIER	VALUE
INTEREST RATE	P11	10.00	UNITS MANUFACTURED PCT.	P21	120.00
AVERAGE INVENTORY PCT.	P23	20.00	ENGINEERING EXPENSE PCT.	P26	5.00
SELLING EXPENSE PCT.	P27	5.00	ADMINISTRATION EXPENSE PCT	P28	10.00
RECEIVABLES PCT.	P31	20.00	DEPRECIATION PERIOD (YRS)	P35	10.00
OTHER INVESTMENT PCT.	P33	5.00			

PERCENTAGE OF BASELINE USED

INPUTS	IDENTIFIER	PCT
TOTAL MARKET	X1	100
MARKET SHARE	X2	100
UNIT PRICE	X3	100
UNIT MANUFACTURING COST	X4	100
R AND D EXPENSE	X5	100
ANNUAL PLANT AND EQUIP.	X6	100

ADD/SUB FROM BASELINE INPUTS

IDENTIFIER	VALUE
A1	0.
A2	0.
A3	.00
A4	0.
A5	0.
A6	0.

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Figure IV-3. Tungsten Case B Input Values

	75	76	77	78	79	80	81	82	83	84
TOTAL MARKET (UNITS)	0.	0.	0.	0.	0.	80300.	85100.	90200.	95600.	101000.
MARKET SHARE (PCT)	.00	.00	.00	.00	.00	.00	.00	2.20	4.20	7.90
UNITS SOLD (UNITS)	0.	0.	0.	0.	0.	0.	0.	1984.	4015.	7979.
UNIT PRICE	0.	0.	0.	0.	0.	0.	0.	442.	442.	442.
SALES	0.	0.	0.	0.	0.	0.	0.	877105.	1774718.	3526718.
OPERATING EXPENSES	0.	0.	0.	24000.	24000.	523000.	1973000.	2655796.	1447833.	2749782.
GROSS PROFITS	0.	0.	0.	-24000.	-24000.	-523000.	-1973000.	-1778691.	326886.	776936.
ANNUAL INVESTMENT	0.	0.	0.	0.	0.	0.	1161000.	1269295.	1383138.	1728129.
CUMULATIVE GROSS PROFITS	0.	0.	0.	-24000.	-48000.	-571000.	-2544000.	-4322691.	-3995805.	-3218870.
BASE FOR INTEREST EXP.	0.	0.	0.	24000.	48000.	571000.	3705000.	5591986.	5378943.	4946999.
INTEREST EXPENSE	0.	0.	0.	2400.	4800.	57100.	370500.	559199.	537894.	494700.
INCOME BEFORE TAXES	0.	0.	0.	-26400.	-28800.	-580100.	-2343500.	-2337890.	-211008.	282236.
TAXES	0.	0.	0.	-12672.	-13824.	-278448.	-1124880.	-1122187.	-101284.	135473.
NET INCOME AFTER TAXES	0.	0.	0.	-13728.	-14976.	-301652.	-1218620.	-1215703.	-109724.	146763.
NET CHANGE IN INVEST.	0.	0.	0.	0.	0.	0.	1161000.	108295.	113843.	344991.
ANNUAL CASH FLOW	0.	0.	0.	-13728.	-14976.	-301652.	-2379620.	-1323997.	-229567.	-198229.
CUMULATIVE CASH FLOW	0.	0.	0.	-13728.	-28704.	-330356.	-2709976.	-4033973.	-4257541.	-4455769.
RETURN ON INVESTMENT(PCT)	.00	.00	.00	.00	.00	.00	.104.96	.95.78	.7.93	8.49
NET INCOME TO SALES (PCT)	.00	.00	.00	.00	.00	.00	.00	-138.60	.6.18	4.16
O P E R A T I N G E X P E N S E										
UNIT MANUFACTURING COST	.00	.00	.00	.00	.00	.00	.00	222.00	222.00	222.00
UNITS MANUFACTURED(UNITS)	0.	0.	0.	0.	0.	0.	0.	2381.	4818.	9575.
COST OF GOODS MFG.	0.	0.	0.	0.	0.	0.	0.	528644.	1069649.	2125606.
AVERAGE INVENTORY***	0.	0.	0.	0.	0.	0.	0.	105729.	213930.	425121.
R AND D EXPENSE	0.	0.	0.	24000.	24000.	523000.	1844000.	1875000.	0.	0.
ENGINEERING EXPENSE	0.	0.	0.	0.	0.	0.	0.	26432.	53482.	106280.
SELLING EXPENSE	0.	0.	0.	0.	0.	0.	0.	43855.	88736.	176336.
ADMINISTRATION EXPENSES	0.	0.	0.	0.	0.	0.	0.	52864.	106965.	212561.
DEPRECIATION EXPENSES**	0.	0.	0.	0.	0.	0.	129000.	129000.	129000.	129000.
TOTAL OPERATING EXPENSES	0.	0.	0.	24000.	24000.	523000.	1973000.	2655796.	1447833.	2749782.
I N V E S T M E N T										
RECEIVABLES (AVG)	0.	0.	0.	0.	0.	0.	0.	175421.	354944.	705344.
INVENTORIES (AVG)	0.	0.	0.	0.	0.	0.	0.	105729.	213930.	425121.
ANNUAL PLANT AND EQUIP.	0.	0.	0.	0.	0.	0.	1290000.	0.	0.	0.
CUMULATIVE PLANT + EQUIP.	0.	0.	0.	0.	0.	0.	1290000.	1290000.	1290000.	1290000.
ANNUAL DEPRECIATION	0.	0.	0.	0.	0.	0.	129000.	129000.	129000.	129000.
CUMULATIVE DEPRECIATION	0.	0.	0.	0.	0.	0.	129000.	258000.	387000.	516000.
NET PLANT + EQUIP.	0.	0.	0.	0.	0.	0.	1161000.	1032000.	903000.	774000.
OTHER INVESTMENT****	0.	0.	0.	0.	0.	0.	0.	43855.	88736.	176336.
NET ANNUAL INVESTMENT	0.	0.	0.	0.	0.	0.	1161000.	1269295.	1383138.	1728129.
PRESENT VALUE OF ANNUAL CASH FLOW			1662752.							

* ASSUME TAX LOSS IS CREDITED AGAINST OTHER BUSINESS INCOME.

** THIS ITEM IS NORMALLY INCLUDED IN VARIOUS OVERHEAD ACCOUNTS.

*** INVENTORY DERIVATION IS HIGHLY SIMPLIFIED, BUT APPROXIMATES MORE COMPLEX METHODS

**** INCLUDES MISC. LIABILITIES SUCH AS ACCOUNTS PAYABLE, RESERVES, Sundry CREDITOR ITEMS

Figure IV-4A. Tungsten Case B Cash Flow Analysis

	85	86	87	88	89	90	91	92	93	94
TOTAL MARKET (UNITS)	107500.	114000.	121000.	128000.	135600.	143800.	152400.	161600.	0.	0.
MARKET SHARE (PCT)	14.90	28.10	33.00	31.30	29.50	27.80	26.20	24.80	.00	.00
UNITS SOLD (UNITS)	16017.	32034.	39930.	40064.	40007.	39976.	39929.	40077.	0.	0.
UNIT PRICE	442.	442.	442.	442.	442.	442.	442.	442.	0.	0.
SALES	7079735.	14159026.	17649060.	17708288.	17680884.	17669569.	17648530.	17713946.	0.	0.
OPERATING EXPENSES	5390108.	10700886.	13294408.	13338421.	13318057.	13309648.	13244014.	13292626.	0.	0.
GROSS PROFITS	1689627.	3458140.	4354652.	4369867.	4362827.	4359920.	4404516.	4421320.	0.	0.
ANNUAL INVESTMENT	2560373.	4796626.	5561829.	5398853.	5212439.	5030378.	5685686.	5574384.	0.	0.
CUMULATIVE GROSS PROFITS	-1529243.	1928896.	6283550.	10653416.	15016243.	19376164.	23780680.	28202000.	0.	0.
BASE FOR INTEREST EXP.	4089615.	2867728.	0.	0.	0.	0.	0.	0.	0.	0.
INTEREST EXPENSE	408962.	286773.	0.	0.	0.	0.	0.	0.	0.	0.
INCOME BEFORE TAXES	1280665.	3171368.	4354652.	4369867.	4362827.	4359920.	4404516.	4421320.	0.	0.
TAXES	614719.	1522256.	2090233.	2097536.	2094157.	2092762.	2114168.	2122234.	0.	0.
NET INCOME AFTER TAXES	665946.	1649111.	2264419.	2272331.	2268670.	2267159.	2290348.	2299086.	0.	0.
NET CHANGE IN INVEST.	832244.	2236253.	765204.	-167976.	-186414.	-182061.	655308.	-111302.	0.	0.
ANNUAL CASH FLOW	-166298.	-587142.	1499215.	2435307.	2455084.	2449220.	1635040.	2410388.	0.	0.
CUMULATIVE CASH FLOW	-4622067.	-5209269.	-3709994.	-1274687.	1180397.	3629617.	5264658.	7675046.	0.	0.
RETURN ON INVESTMENT (PCT)	26.01	34.38	40.71	42.09	43.52	45.07	40.28	41.24	.00	.00
NET INCOME TO SALES (PCT)	9.41	11.65	12.83	12.83	12.83	12.83	12.98	12.98	.00	.00
O P E R A T I N G E X P E N S E										
UNIT MANUFACTURING COST	222.00	222.00	222.00	222.00	222.00	222.00	222.00	222.00	.00	.00
UNITS MANUFACTURED (UNITS)	19221.	38441.	47916.	48077.	48007.	47972.	47915.	48092.	0.	0.
COST OF GOODS MFG.	4267062.	8533858.	10637352.	10673050.	10656533.	10649713.	10637032.	10676460.	0.	0.
AVERAGE INVENTORY***	853412.	1706772.	2127470.	2134610.	2131307.	2129943.	2127406.	2135292.	0.	0.
R AND D EXPENSE	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
ENGINEERING EXPENSE	213353.	426693.	531868.	533652.	532827.	532486.	531852.	533823.	0.	0.
SELLING EXPENSE	353987.	707951.	882453.	885414.	884044.	883478.	882426.	885697.	0.	0.
ADMINISTRATION EXPENSES	426706.	853386.	1063735.	1067305.	1065653.	1064971.	1063703.	1067646.	0.	0.
DEPRECIATION EXPENSES**	129000.	179000.	179000.	179000.	179000.	179000.	129000.	129000.	0.	0.
TOTAL OPERATING EXPENSES	5390108.	10700886.	13294408.	13338421.	13318057.	13309648.	13244014.	13292626.	0.	0.
I N V E S T M E N T										
RECEIVABLES (AVG)	1415947.	2831806.	3529812.	3541658.	3536177.	3533914.	3529706.	3542789.	0.	0.
INVENTORIES (AVG)	853412.	1706772.	2127470.	2134610.	2131307.	2129943.	2127406.	2135292.	0.	0.
ANNUAL PLANT AND EQUIP.	0.	500000.	0.	0.	0.	0.	790000.	0.	0.	0.
CUMULATIVE PLANT + EQUIP.	1290000.	1790000.	1790000.	1790000.	1790000.	1790000.	2580000.	2580000.	0.	0.
ANNUAL DEPRECIATION	129000.	179000.	179000.	179000.	179000.	179000.	129000.	129000.	0.	0.
CUMULATIVE DEPRECIATION	645000.	824000.	1003000.	1182000.	1361000.	1540000.	1669000.	1798000.	0.	0.
NET PLANT + EQUIP.	645000.	966000.	787000.	608000.	429000.	250000.	911000.	782000.	0.	0.
OTHER INVESTMENT****	353987.	707951.	882453.	885414.	884044.	883478.	882426.	885697.	0.	0.
NET ANNUAL INVESTMENT	2560373.	4796626.	5561829.	5398853.	5212439.	5030378.	5685686.	5574384.	0.	0.
PRESENT VALUE OF ANNUAL CASH FLOW			1662752.							

* ASSUME TAX LOSS IS CREDITED AGAINST OTHER BUSINESS INCOME.
 ** THIS ITEM IS NORMALLY INCLUDED IN VARIOUS DEFERRED ACCOUNTS.
 *** INVENTORY DERIVATION IS HIGHLY SIMPLIFIED, BUT APPROXIMATES MORE COMPLEX METHODS
 **** INCLUDES MISC. LIABILITIES SUCH AS ACCOUNTS PAYABLE, RESERVES, Sundry CREDITORS ITEMS

Figure IV-4B. Tungsten Case B Cash Flow Analysis

INPUTS:	75	76	77	78	79	80	81	82	83	84
TOTAL MARKET (UNITS)	0.	0.	0.	0.	0.	80900.	85100.	90200.	95600.	101000.
MARKET SHARE (PCT)	0.	0.	0.	0.	0.	0.	0.	5.	9.	15.
UNIT PRICE	0.	0.	0.	0.	0.	0.	0.	442.	442.	442.
UNIT MANUFACTURING COST	.00	.00	.00	.00	.00	.00	.00	177.00	177.00	177.00
R AND D EXPENSE	0.	0.	0.	24000.	24000.	523000.	1844000.	1875000.	0.	0.
ANNUAL PLANT AND EQUIP.	0.	0.	0.	0.	0.	0.	1290000.	0.	0.	0.
INPUTS:	85	86	87	88	89	90	91	92	93	94
TOTAL MARKET (UNITS)	107500.	114000.	121000.	128000.	135600.	143800.	152400.	161600.	0.	0.
MARKET SHARE (PCT)	25.	30.	35.	40.	45.	50.	50.	50.	0.	0.
UNIT PRICE	442.	442.	442.	442.	442.	442.	442.	442.	0.	0.
UNIT MANUFACTURING COST	177.00	177.00	177.00	177.00	177.00	177.00	177.00	177.00	.00	.00
R AND D EXPENSE	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
ANNUAL PLANT AND EQUIP.	0.	500000.	0.	0.	0.	0.	790000.	0.	0.	0.
PARAMETRIC PERCENTAGES:										
PARAMETER	IDENTIFIER	VALUE	PARAMETER	IDENTIFIER	VALUE					
INTEREST RATE	P11	10.00	UNITS MANUFACTURED PCT.	P21	120.00					
AVERAGE INVENTORY PCT.	P23	20.00	ENGINEERING EXPENSE PCT.	P26	5.00					
SELLING EXPENSE PCT.	P27	5.00	ADMINISTRATION EXPENSE PCT	P28	10.00					
RECEIVABLES PCT.	P31	20.00	DEPRECIATION PERIOD (YRS)	P35	10.00					
OTHER INVESTMENT PCT.	P38	5.00								
PERCENTAGE OF BASELINE USED										
INPUTS	IDENTIFIER	PCT	ADD/SUB FROM BASELINE	INPUTS	IDENTIFIER	VALUE				
TOTAL MARKET	X1	100		A1		0.				
MARKET SHARE	X2	100		A2		0.				
UNIT PRICE	X3	100		A3		.00				
UNIT MANUFACTURING COST	X4	100		A4		0.				
R AND D EXPENSE	X5	100		A5		0.				
ANNUAL PLANT AND EQUIP.	X6	100		A6		0.				

Figure IV-5. Tungsten Case C Input Values

	75	76	77	78	79	80	81	82	83	84
TOTAL MARKET (UNITS)	0.	.	0.	0.	0.	80300.	85100.	90200.	95600.	101000.
MARKET SHARE (PCT)	.00	.00	.00	.00	.00	.00	.00	5.00	9.00	18.00
UNITS SOLD (UNITS)	0.	0.	0.	0.	0.	0.	0.	4510.	8604.	18180.
UNIT PRICE	0.	0.	0.	0.	0.	0.	0.	442.	442.	442.
SALES	0.	0.	0.	0.	0.	0.	0.	1993420.	3802968.	8035560.
OPERATING EXPENSES	0.	0.	0.	24000.	24000.	523000.	1973000.	3205284.	2420761.	4971425.
GROSS PROFITS	0.	0.	0.	-24000.	-24000.	-523000.	-1973000.	-1211864.	1382207.	3064135.
ANNUAL INVESTMENT	0.	0.	0.	0.	0.	0.	0.	1161000.	1522598.	1838943.
CUMULATIVE GROSS PROFITS	0.	0.	0.	-24000.	-48000.	-571000.	-2544000.	-3755864.	-2373657.	690478.
BASE FOR INTEREST EXP.	0.	0.	0.	24000.	48000.	571000.	3705000.	5278461.	4212600.	2061142.
INTEREST EXPENSE	0.	0.	0.	2400.	4800.	57100.	370500.	527846.	421260.	206114.
INCOME BEFORE TAXES	0.	0.	0.	-26400.	-28800.	-580100.	-2343500.	-1739710.	960947.	2858021.
TAXES	0.	0.	0.	-12672.	-13824.	-278448.	-1124880.	-835061.	461254.	1371850.
NET INCOME AFTER TAXES	0.	0.	0.	-13728.	-14976.	-301652.	-1218620.	-904649.	499692.	1486171.
NET CHANGE IN INVEST.	0.	0.	0.	0.	0.	0.	1161000.	361598.	316345.	912677.
ANNUAL CASH FLOW	0.	0.	0.	-13728.	-14976.	-301652.	-2379620.	-1266247.	183347.	573494.
CUMULATIVE CASH FLOW	0.	0.	0.	-13728.	-28704.	-330356.	-2709976.	-3976223.	-3792876.	-3219382.
RETURN ON INVESTMENT (PCT)	.00	.00	.00	.00	.00	.00	-104.96	-59.41	27.17	54.01
NET INCOME TO SALES (PCT)	.00	.00	.00	.00	.00	.00	.00	-45.38	13.14	18.49

OPERATING EXPENSE

UNIT MANUFACTURING COST	.00	.00	.00	.00	.00	.00	.00	177.00	177.00	177.00
UNITS MANUFACTURED (UNITS)	0.	0.	0.	0.	0.	0.	0.	5412.	10325.	21816.
COST OF GOODS MFG.	0.	0.	0.	0.	0.	0.	0.	957924.	1827490.	3861432.
AVERAGE INVENTORY***	0.	0.	0.	0.	0.	0.	0.	191585.	365498.	772286.
R AND D EXPENSE	0.	0.	0.	24000.	24000.	523000.	1844000.	1875000.	0.	0.
ENGINEERING EXPENSE	0.	0.	0.	0.	0.	0.	0.	47896.	91374.	193072.
SELLING EXPENSE	0.	0.	0.	0.	0.	0.	0.	99671.	190148.	401778.
ADMINISTRATION EXPENSES	0.	0.	0.	0.	0.	0.	0.	95792.	182749.	386143.
DEPRECIATION EXPENSES**	0.	0.	0.	0.	0.	0.	129000.	129000.	129000.	129000.
TOTAL OPERATING EXPENSES	0.	0.	0.	24000.	24000.	523000.	1973000.	3205284.	2420761.	4971425.

INVESTMENT

RECEIVABLES (AVG)	0.	0.	0.	0.	0.	0.	0.	398684.	760594.	1607112.
INVENTORIES (AVG)	0.	0.	0.	0.	0.	0.	0.	191585.	365498.	772286.
ANNUAL PLANT AND EQUIP.	0.	0.	0.	0.	0.	0.	1290000.	0.	0.	0.
CUMULATIVE PLANT + EQUIP.	0.	0.	0.	0.	0.	0.	1290000.	1290000.	1290000.	1290000.
ANNUAL DEPRECIATION	0.	0.	0.	0.	0.	0.	129000.	129000.	129000.	129000.
CUMULATIVE DEPRECIATION	0.	0.	0.	0.	0.	0.	129000.	258000.	387000.	516000.
NET PLANT + EQUIP.	0.	0.	0.	0.	0.	0.	1161000.	1032000.	903000.	774000.
OTHER INVESTMENT****	0.	0.	0.	0.	0.	0.	0.	99671.	190148.	401778.
NET ANNUAL INVESTMENT	0.	0.	0.	0.	0.	0.	1161000.	1522598.	1838943.	2751620.
PRESENT VALUE OF ANNUAL CASH FLOW			8,21221.							

* ASSUME TAX LOSS IS CREDITED AGAINST OTHER BUSINESS INCOME.

** THIS ITEM IS NORMALLY INCLUDED IN VARIOUS OVERHEAD ACCOUNTS.

*** INVENTORY DERIVATION IS HIGHLY SIMPLIFIED, BUT APPROXIMATES MORE COMPLEX METHODS

**** INCLUDES MISC. LIABILITIES SUCH AS ACCOUNTS PAYABLE, RESERVES, SUNDRY CREDITOR ITEMS

Figure IV-6A. Tungsten Case C Cash Flow Analysis

	85	86	87	88	89	90	91	92	93	94
TOTAL MARKET (UNITS)	107500.	114000.	121000.	128000.	135600.	143800.	152400.	161600.	0.	0.
MARKET SHARE (PCT)	25.00	30.00	35.00	40.00	45.00	50.00	50.00	50.00	.00	.00
UNITS SOLD (UNITS)	26875.	34200.	42350.	51200.	61020.	71900.	76200.	80800.	0.	0.
UNIT PRICE	442.	442.	442.	442.	442.	442.	442.	442.	0.	0.
SALES	11878750.	15116400.	18718700.	22630400.	26970840.	31779800.	33680400.	35713600.	0.	0.
OPERATING EXPENSES	7287425.	9288512.	11459346.	13816632.	16432287.	19330284.	20425632.	21650888.	0.	0.
GROSS PROFITS	4591325.	5827888.	7259354.	8813768.	10538553.	12449516.	13254768.	14062712.	0.	0.
ANNUAL INVESTMENT	3568462.	4686276.	5393833.	6177536.	7066756.	8071282.	9200036.	9571424.	0.	0.
CUMULATIVE GROSS PROFITS	5281803.	11109691.	18369045.	27182813.	37721366.	50170882.	63425650.	77488362.	0.	0.
BASE FOR INTEREST EXP.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
INTEREST EXPENSE	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
INCOME BEFORE TAXES	4591325.	5827888.	7259354.	8813768.	10538553.	12449516.	13254768.	14062712.	0.	0.
TAXES	2203836.	2797386.	3484490.	4230609.	5058505.	5975768.	6362289.	6750102.	0.	0.
NET INCOME AFTER TAXES	2387489.	3030502.	3774864.	4583159.	5480047.	6473748.	6892479.	7312610.	0.	0.
NET CHANGE IN INVEST.	816842.	1117813.	707557.	783703.	889220.	1004526.	1128754.	371388.	0.	0.
ANNUAL CASH FLOW	1570647.	1912688.	3067307.	3799456.	4590828.	5469222.	5763725.	6941222.	0.	0.
CUMULATIVE CASH FLOW	-1648735.	263953.	3331260.	7130716.	11721544.	17190766.	22954491.	29895714.	0.	0.
RETURN ON INVESTMENT(PCT)	66.91	64.67	69.98	74.19	77.55	80.21	74.92	76.40	.00	.00
NET INCOME TO SALES (PCT)	20.10	20.05	20.17	20.25	20.32	20.37	20.46	20.48	.00	.00

O P E R A T I N G E X P E N S E

UNIT MANUFACTURING COST	177.00	177.00	177.00	177.00	177.00	177.00	177.00	177.00	.00	.00
UNITS MANUFACTURED(UNITS)	32250.	41040.	50820.	61440.	73224.	86280.	91440.	96960.	0.	0.
COST OF GOODS MFG.	5708250.	7264080.	8995140.	10874880.	12960648.	15271560.	16184880.	17161920.	0.	0.
AVERAGE INVENTORY***	1141650.	1452816.	1799028.	2174976.	2592130.	3054312.	3236976.	3432384.	0.	0.
R AND D EXPENSE	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
ENGINEERING EXPENSE	285412.	363204.	449757.	543744.	648032.	763578.	809244.	858096.	0.	0.
SELLING EXPENSE	593937.	755820.	935935.	1131520.	1348542.	1588990.	1684020.	1785680.	0.	0.
ADMINISTRATION EXPENSES	570825.	726408.	899514.	1087488.	1296065.	1527156.	1618488.	1716192.	0.	0.
DEPRECIATION EXPENSES**	129000.	179000.	179000.	179000.	179000.	179000.	129000.	129000.	0.	0.
TOTAL OPERATING EXPENSES	7287425.	9288512.	11459346.	13816632.	16432287.	19330284.	20425632.	21650888.	0.	0.

I N V E S T M E N T

RECEIVABLES (AVG)	2375750.	3023280.	3743740.	4526080.	5394168.	6355960.	6736080.	7142720.	0.	0.
INVENTORIES (AVG)	1141650.	1452816.	1799028.	2174976.	2592130.	3054312.	3236976.	3432384.	0.	0.
ANNUAL PLANT AND EQUIP.	0.	500000.	0.	0.	0.	0.	790000.	0.	0.	0.
CUMULATIVE PLANT + EQUIP.	1290000.	1790000.	1790000.	1790000.	1790000.	1790000.	2580000.	2580000.	0.	0.
ANNUAL DEPRECIATION	129000.	179000.	179000.	179000.	179000.	179000.	129000.	129000.	0.	0.
CUMULATIVE DEPRECIATION	645000.	824000.	1003000.	1182000.	1361000.	1540000.	1669000.	1798000.	0.	0.
NET PLANT + EQUIP.	645000.	966000.	787000.	608000.	429000.	250000.	911000.	782000.	0.	0.
OTHER INVESTMENT****	593937.	755820.	935935.	1131520.	1348542.	1588990.	1684020.	1785680.	0.	0.
NET ANNUAL INVESTMENT	3568462.	4686276.	5393833.	6177536.	7066756.	8071282.	9200036.	9571424.	0.	0.
PRESENT VALUE OF ANNUAL CASH FLOW			8521221.							

* ASSUME TAX LOSS IS CREDITED AGAINST OTHER BUSINESS INCOME.

** THIS ITEM IS NORMALLY INCLUDED IN VARIOUS OVERHEAD ACCOUNTS.

*** INVENTORY DERIVATION IS HIGHLY SIMPLIFIED, BUT APPROXIMATES MORE COMPLEX METHODS

**** INCLUDES MISC. LIABILITIES SUCH AS ACCOUNTS PAYABLE, RESERVES, SUNDRY CREDITOR ITEMS

Figure IV-6B. Tungsten Case C Cash Flow Analysis

Changes in assumptions could be made to increase the attractiveness of the conceptual tungsten venture:

Increase unit price

Decrease unit manufacturing cost

Decrease other operating expenses

Increase market share

Decrease R&D expense

Since the operating results in the later years of the forecast are good, the increase of market share would have a salutary effect on cumulative cash flow and achievement of breakeven. This would not be unwarranted, based on the assumed attractiveness of the long-life x-ray target, and assuming that there was limited access to the tungsten space process by competitors. The further analysis of these possibilities, and of the concept itself are beyond the scope of this study but the possibilities, although not as promising as other products studied, warrant further investigation before final conclusions are reached. Total market (demand) and market share should especially be examined, since the baseline chosen was conservative, and may even have been harsh.

Figure IV-7 plots the key financial measures of the tungsten processing venture.

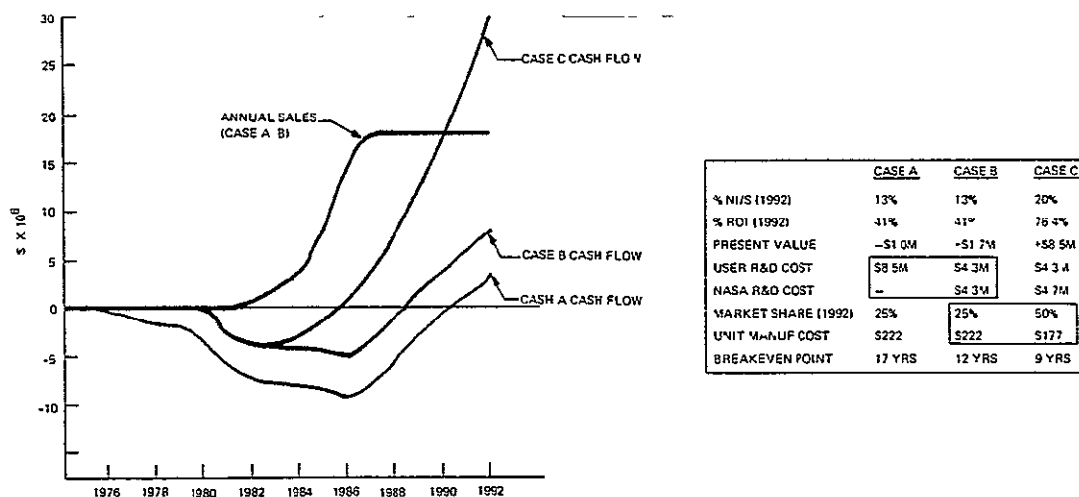


Figure IV-7. Tungsten Processing Cash Flow

SECTION V

MARKET ANALYSIS

V.1 INTRODUCTION

The market addressed is that for the demand for tungsten X-ray tube targets in the period 1980-1992. The target is nominally 4-inch diameter, with a thin tungsten track bonded to a molybdenum substrate. This demand for targets translates to an equivalent need for high purity, fine-grained, low DBTT tungsten, as expected from space processing. The space product which is produced is a nominally 1.2375 kg sphere (5 cm diameter) which is subsequently formed into target segments. Each segment consists of enough tungsten to make one x-ray tube target.

The demand for X-ray tube targets of present design is reasonably well known, while the price and demand for targets using space-processed tungsten is conjectural at this time.

A description of the concept of the business which would address the market is given in the following paragraphs.

V.1.1 ORGANIZATION

The business, under the direction of a product manager, is part of an existing manufacturing organization which uses tungsten in its product lines. The space-processed tungsten is interrelated with other manufacturing activities as follows:

- a) Powdered tungsten of an appropriate purity is obtained from an existing tungsten press-and-sinter operation within the company.
- b) The space-processed tungsten is rolled, stamped, bonded, etc., in an existing X-ray tube target production facility within the company.
- c) Most of the finished targets are assembled into X-ray tubes in an existing facility in the company and the tubes are distributed and sold through an

existing company sales and distribution channel. Some targets are sold as finished products to other X-ray tube manufacturers. High-quality tungsten scrap is sold to manufacturers of specialty tungsten products.

V.1.2 FACILITIES AND EQUIPMENT

A starting-tungsten preparation facility is established in existing production plant space. Conventional equipment for inspection, pressing, sintering and packaging is provided.

Space facilities (2 units) are maintained for transport and in-orbit processing of tungsten using the Space Shuttle. One unit is in space operation while the other is being refurbished. A small staff is assigned to preparation, delivery, return, and refurbishment of the facility and handling of in-process materials.

A target ring rolling, stamping, and bonding facility is established in existing production plant space. Conventional equipment is provided for this process. Substrates for the target rings are obtained from existing target production lines. Subsequent process steps for assembly and test of X-ray tubes using the space-processed tungsten targets are done on existing production lines. The X-ray tube assembly and test process is excluded from the tungsten venture as defined in this study.

V.1.3 WASTE PRODUCTS/SALVAGE

The scrap obtained from stamping of target rings from rolled sheet is sold either as-is or given further processing prior to sale to other manufacturers.

V.1.4 INITIAL R&D

To reach production status, the business has incurred a significant expense in research of tungsten processing methods and development of an in-space processing facility to plot and to full scale production facility. This R&D expense amounts to \$4.3 million,

spread over 5 years, assuming that process feasibility has been demonstrated in government-funded projects.

V.1.5 CONTINUING R&D (ENGINEERING DEVELOPMENT/ADVANCED ENGINEERING)

The business maintains a continuing R&D (product development) program of 5% of sales to assure a competitive product.

V.1.6 SPACE SHUTTLE SERVICES

Arrangements have been made with NASA for regular (say monthly) shuttle services, including up-transport, on-orbit operations in low earth orbit, and down-transport services. On-orbit operating times are 7 days or more per flight. The mechanics of using shuttle services were established during the R&D phase, and service charges, legal considerations, schedules, etc., have been agreed to and documented.

V.1.7 INVENTORY AND RECEIVABLES

The business operates at a relatively even month-to-month production level. Net inventory on an annual basis is 20% of sales, and receivables average 20% of sales.

V.2 PRODUCT BENEFITS

The key benefits to the user of the new X-ray tube containing the improved tungsten would be:

- increased tube life (perhaps 50% longer life)
- increased safety (by virtue of a target which could withstand high stress over a longer period)
- reduced maintenance (tube replacement) down time

The tube manufacturer would realize further benefits in the form of:

- reduced target rejects during manufacture
- reduced tube failures during the warranty period
- avoidance of dependency on rhenium

V.3 COMPETITIVE PRODUCTS AND COMPETITORS

The only initial competitive product to the new X-ray tube target would be the present tungsten/rhenium/molybdenum target. The new target would compete against this incumbent product by offering the benefits given in paragraph V.2 at a tube price which gave more tube hours per dollar than the incumbent product. After introduction of the new tube, it is reasonable to assume other producers would enter the world market with a similar space-processed tungsten product and that the market volume would have to be shared from that time onward.

V.4 POTENTIAL ALTERNATIVES

The most serious alternatives to the space-processed tungsten approach are: (1) the evolution of the present tungsten/rhenium target to a performance level approaching 50% greater life, and (2) the potential ability to process low DBTT tungsten on the ground, with resultant avoidance of the high space processing costs. At this time, neither of these alternatives shows high promise of success.

V.5 POTENTIAL BUYERS

The potential buyers of space-processed tungsten spheres would include present target manufacturers such as Metallwerk Plansee and General Electric-Medical Systems Division. Potential buyers of the new X-ray tube targets would include the present X-ray tube manufacturers, such as EIMAC, Dunlee, Eureka, Machlett, Phillips, Siemens, Toshiba, Comet, Crisa, French CGR, and General Electric-Medical Systems Division.

V.6 MARKET FORECAST

The market has been forecast on the basis of X-ray tube targets and the assumption that all targets would be of 4-inch diameter. Three-inch and five-inch targets are also in use, but use of five-inch targets is not significant, and there appears to be a strong movement from use of three-inch targets to use of four-inch targets. The forecasted demand for four-inch targets in the period 1980-1992 (U.S. and world) is as follows.

Assuming that tungsten layers for five targets can be formed from one space-processed tungsten sphere of net weight 1.2375 kg (1.25 kg gross weight less 1% evaporation losses), the demand for tungsten spheres is one-fifth of annual target demand. The demand for tungsten spheres (assuming only an X-ray tube application) is then as follows.

<u>Year</u>	<u>World</u>	<u>U.S.</u>	<u>Year</u>	<u>World</u>	<u>U.S.</u>
1980	80,300	26,800	1986	114,000	38,000
1981	85,100	28,400	1987	121,000	40,300
1982	90,200	30,100	1988	128,000	42,700
1983	95,600	31,900	1989	135,600	45,200
1984	101,000	33,700	1990	143,800	47,900
1985	107,500	35,800	1991	152,400	50,800
			1992	161,600	53,900

Figure V-1. World and U.S. Demand for X-Ray Tube Targets, 1980-1992

<u>Year</u>	<u>World</u>	<u>U.S.</u>	<u>Year</u>	<u>World</u>	<u>U.S.</u>
1980	16,060	5,360	1986	22,800	7,600
1981	17,020	5,680	1987	24,200	8,060
1982	18,040	6,020	1988	25,600	8,540
1983	19,120	6,380	1989	27,120	9,040
1984	20,200	6,740	1990	28,760	9,580
1985	21,500	7,160	1991	30,480	10,160
			1992	32,320	10,780

Figure V-2. World and U.S. Demand for 1.2375 Kg Tungsten Spheres 1980-1992

The effect of the longer tube life on demand has been disregarded in this study, but would need to be considered in the future, as more accurate forecasts are attempted.

V.7 PRODUCT QUANTITIES AND PRICING

The forecast of market share (units sold) is based on achieving about 25% of the world market in the 1987-1992 period with first sales in 1982, and sphere production as follows:

<u>Year</u>	<u>Sphere Production</u>	<u>Year</u>	<u>Sphere Production</u>
1980	0	1986	6,400
1981	0	1987	8,000
1982	400	1988	8,000
1983	800	1989	8,000
1984	1,600	1990	8,000
1985	3,200	1991	8,000
		1992	8,000

Figure V-3. Forecasted Production of Tungsten Spheres (1.2375 Kg each), 1980-1992

The significance of the tungsten sphere as a unit for projection is that it conveniently describes the process throughput from raw tungsten preparation through space processing and up to the point of rolling out tungsten sheet.

The price of a tungsten target fabricated from space-processed tungsten is quite difficult to determine, and figures presented here must be used with caution. However, using a rough analysis of the future X-ray tube fabrication costs, and relating these to present-day tube fabrication costs and prices, it is thought that a tube manufacturer could afford a cost of \$557.41 for a finished target which offered 50% longer tube life. This presumes that the target manufacturer is able to dispose of tungsten scrap at a price of \$100/Kg. The cost contribution (selling price) of the tungsten layer is estimated at \$442.53, so that a sphere which satisfies the requirements for five target layers is worth (5 x \$442.53) or \$2212.65 per tungsten sphere.

No attempt has been made to modify this sphere price over the 1982-1992 period, owing to the tenuous nature of the estimate.

Using the sphere production figures given earlier, and the per-target price, a very preliminary sales forecast can be given as follows: Sales of finished targets = (no. of spheres x 5 x \$557.41/finished target) and Sales of target segments = (no. of spheres x 5 x \$442.53/Target segment).

<u>Year</u>	<u>Finished Target Sales (\$)</u>	<u>Target Segment Sales \$</u>	<u>Year</u>	<u>Finished Target Sales (\$)</u>	<u>Target Segment Sales (\$)</u>
1980	0	0	1986	17,827 K	14161 K
1981	0	0	1987	22,296 K	17701 K
1982	1,115 K	885 K	1988	22,296 K	17701 K
1983	2,230 K	1770 K	1989	22,296 K	17701 K
1984	4,459 K	3540 K	1990	22,296 K	17701 K
1985	8,919 K	7080 K	1991	22,296 K	17701 K
			1992	22,296 K	17701 K

Figure V-4. Forecasted Sales

There is no guarantee that uses can be found for the sheet scrap remaining after the targets are cut from rolled spheres. However, possible uses include dental x-ray tube targets, high temperature contacts and fixtures for high temperature vacuum and hydrogen furnaces and nuclear reactor applications. The lowest possible price of this scrap would be that paid for raw tungsten, or about \$33/kg. A more likely application will be one which calls for many small pieces of low DBTT tungsten (sheet thickness about 0.040 inch) for a very high temperature environments or simply for very high purity tungsten in which case a scrap value of well above the \$100/kg value assumed, could be achieved.

V.8 PRODUCT LIFE CYCLE

The product life cycle assumes a fairly rapid growth to high-level sales of the improved X-ray tube, once a full scale production capability has been achieved. It also assumes that marketing efforts have been successful in the 1975-1981 period, in educating potential customers as to the benefits of the new tube, so that any reluctance to switch to the new tube has been removed. The life cycle forecasted is:

<u>Phase</u>	<u>From</u>	<u>To</u>
Introduction	1981	1984
Growth	1985	1986
Maturity	1987	1997
Decline	1998	1999
Exit	1999	2000

Figure V-5. Forecasted Life Cycle

The rapid decline and exit phases assume that a new technology has been developed and that the acceptance of the new-technology product has been as rapid as that shown for the improved x-ray tube in the 1984-1987 period.

SECTION VI

COST/VALUE FOR PRODUCTION

VI.0 TUNGSTEN PROCESSING

This section presents the baseline production concept for producing tungsten x-ray target segments, along with the assumptions and key findings for the product venture. It must be remembered that all figures given here are conceptual only, and are subject to change upon further and more detailed investigation.

VI.1 FLIGHTS AND RESOURCES REQUIRED FOR PILOT PLANT AND FULL SCALE PRODUCTION

The tungsten target production process includes a series of ground-space-ground process steps with one in-space process step required, that of zero-g levitation, heat, degas, melt, and supercooling of tungsten charges. A throughput analysis, unit product cost breakdown, and rough breakdowns of associated costs are provided in the following paragraphs.

VI.1.1 ANALYSIS OF PRODUCT VOLUME AND TIME VS PAYLOAD CAPACITY AND TIME

The forecasted sales volume of target segments (each of which consists of sufficient space-processed tungsten to produce one x-ray tube target layer) begins at a volume of about 2000 per year in 1982 and grows to a level of about 40,000 units per year by 1987, based on a market share of 25-30%. The tungsten levitation/melt facility envisioned would process 600 charges (5 cm. diameter, 1.25 kg. initial weight) per 7-day flight, which equates to 2556 target segments at a net yield of 4.26 segments per charge. Thus in the first year of production, a single 7-day flight would suffice. At full scale production of 40,000 units or 9890 charges per year, 17 weeks production (or its equivalent) would suffice. The nature of the tungsten space facility (heavy, with special power arrangements) suggests that once launched, maximum use would be made of the opportunity, perhaps independent of current production needs.

The various possibilities for using smaller facilities, and smaller charges, with more frequent launches have not been examined in this study. In general, it presently appears that processing of larger charges (assuming that sufficient power is available) is more efficient than processing of smaller charge diameters, although other considerations may ultimately dictate the charge dimensions.

A throughput analysis for the ground and in-space steps is shown in Figure VI-1, for an annual throughput of 3000 kg of space-processed tungsten (about 10,000 target segments final output).

VI.1.2 ANALYSIS OF PROCESSING SUPPORT REQUIREMENTS VS SHUTTLE/ SPACELAB AVAILABLE RESOURCES

The tungsten space processing facility is conceived of as being self-contained, except for special arrangements for input power and periodic crew attention. The facility would be initially launched with a full input cartridge or magazine containing up to 600 tungsten charges for one week's operation and an empty output cartridge. Movement of charges from the input cartridge through the processing chamber and into the output cartridge would be completely automated, so that continuous operator attention would not be required. At the end of the one-week cycle, the output cartridge would be returned to ground and another full input cartridge would be installed.

Shrinkage of the tungsten charges during processing (as a result of evaporation during the heat/melt cycle) is expected to be less than 5% and as low as 1%, so that the output weight will be essentially the same as input weight. This also means that plating out of tungsten in the chamber should not present a problem during production runs at the level contemplated. An average of 2 man hours per day of crew time has been assumed, including cartridge installation and removal time. The input power requirement presents the most challenging aspect of in-orbit support for the tungsten facility. At an energy level of 10.6 KWH per 1.25 kg charge, and 600 charges per week, 6360 KWH are required, with an average power input of 20-30 KW and a peak input of perhaps 45-50 KW. As explained elsewhere in this report, the study has

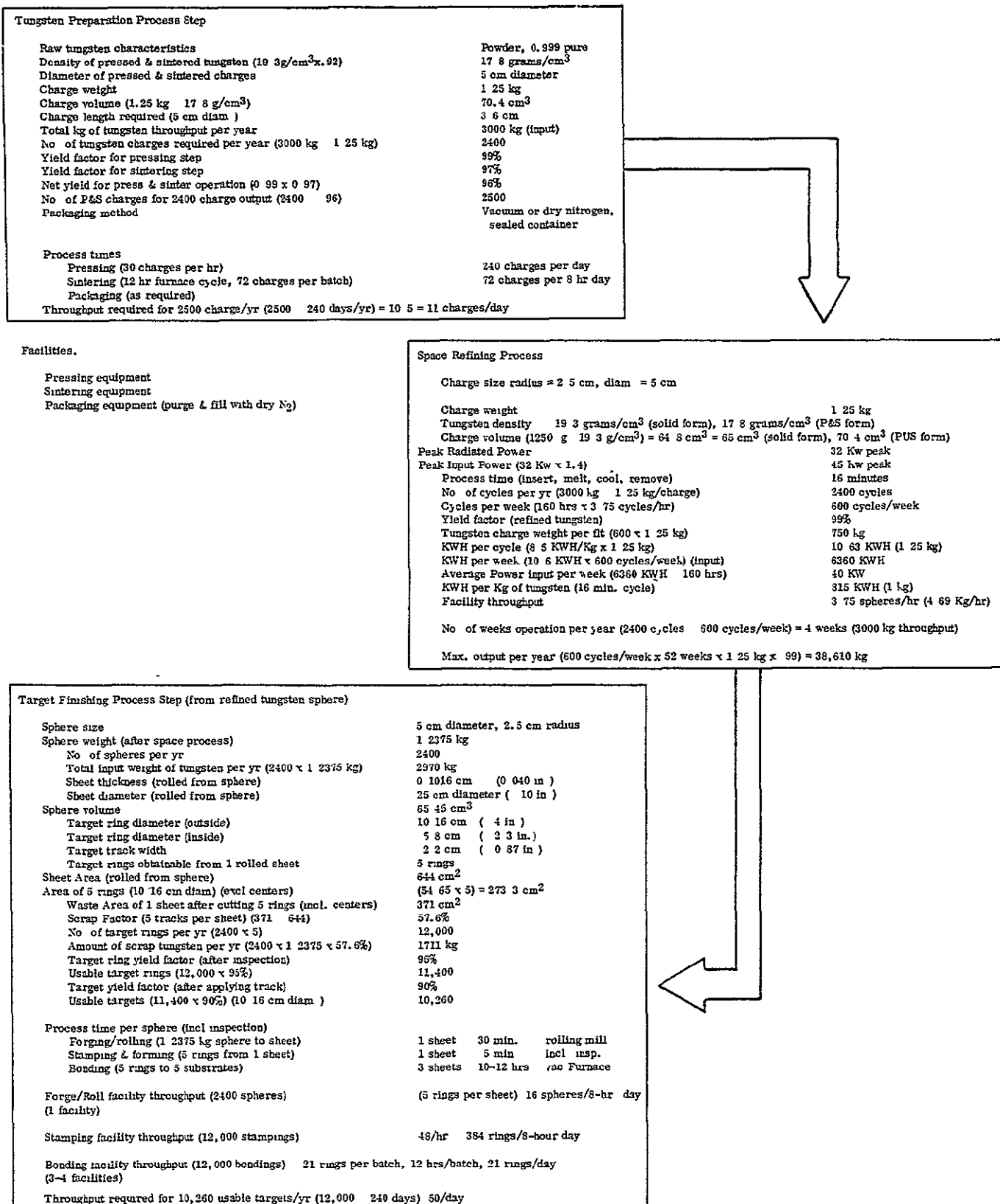


Figure VI-1. Tungsten Process Throughput Analysis

VI-3/VI-4

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assumed that the space support agency will make such a power source available at a cost of \$40 per KWH. This action appears feasible, but whether it will be done in the time frame 1982-1992 will determine the scale of production of tungsten and other energy-intensive products in that time period. An alternative approach, to use direct solar energy concentration was not developed in the study, but could be a viable method. This approach would lead to a different facility concept than was used in this study, which assumed an electrical rather than heat energy input to the facility.

VI.1.3 DETERMINE OF NUMBER OF FLIGHTS FOR PILOT PLANT AND PRODUCTION

A baseline assumption of one flight per year has been used, with cartridge resupply, relative to a nominal annual throughput of, say, 10,000 charges per year. Assuming the facility were operated continuously, and returned for refurbishment once per year, the facility could probably produce enough tungsten to satisfy the total world demand for the tungsten layers for x-ray tube targets. The only variable in the once-per-year flight requirement would be in the flight duration, which is estimated at one week initially, growing to 17 weeks by 1987 (40,000 target segments per year). No attempt has been made to assess the impact of seasonal production demand, or production for long-term inventory, which eventually would influence the planning of production flights.

VI.1.4 DETERMINATION OF RESOURCES REQUIRED FOR PILOT PLANT AND PRODUCTION

A summary of the production resource requirements is shown in Figure VI-2. Plant and equipment requirements are roughly estimated as shown in Figure VI-3.

VI.2 ANALYSIS OF PRODUCTION COSTS

A breakdown of the manufacturing costs by process step for an annual production of 6240 charges is shown in Figure VI-4. The unit cost of 221.52 per target segment, rounded to \$222, was used for analyzing the tungsten business and was used for all

Materials

Raw (pressed and sintered) tungsten
Liquid nitrogen
Molybdenum substrates

Services

Shuttle transport and in-orbit support

Equipment

Tungsten charge preparation equipment (see Plant & Equipment List)
Target stamping, bonding & finishing equipment

Facilities

Tungsten research laboratory
Raw tungsten preparation facility
X-ray target layer & target production facility
Space facility preparation & refurbishment facility

Special Manpower Skills

X-ray tube development & production engineers
Tungsten metallurgist
Heavy metal levitation/melt specialists/engineers

Figure VI-2. Tungsten Production Resource Requirements Summary

	<u>81</u>	<u>82</u>	<u>83</u>	<u>84</u>	<u>85</u>	<u>86</u>	<u>87</u>	<u>88</u>	<u>89</u>	<u>90</u>	<u>91</u>
<u>Tungsten Preparation</u>											
Press	(1) 200K									(1) 200K	
Sintering Furnace	(1) 85K									(1) 85K	
Packaging Equip.	(1) 5K									(1) 5K	
	<u>290K</u>										
<u>Space Processing</u>											
Space Facility	(2) 1000K					(1) 500K	-	-	-	-	(1) <u>500K</u>
Subtotal	<u>1290K</u>										<u>790K</u>
(used for financial analysis of target segments)											
<u>Target Finishing</u>											
Forge	(1) 80K										
Rolling Mill	(1) 90K			(1) 90K		(1) 90K					
Stamping Mill	(1) 30K										
Bonding Furnace	(1) 85K	(1) 85K	85K	(1) 85K	(1) 85K	(1) 85K					
Machining Grinders	(1) <u>20K</u>	<u>-</u>	<u>20K</u>	<u>(1) 20K</u>	<u>(2) 40K</u>	<u>(1) 20K</u>					
	305K		105K	195K	125K	195K	-	-	-	-	
Total	1595K	85K	105K	195K	125K	695K	-	-	-	-	790K

Figure VI-3. Tungsten Plant & Equipment Requirements for Production

Basis: 6240 tungsten charges per year, 5 segments per target = 31,200 segments

<u>Raw Tungsten Preparation</u>	<u>Annual Cost</u>	<u>Unit Cost</u>
Direct Material (6240x1.25kgx\$33/kg)	\$ 257K	
Direct Labor (6240 ÷ 10 charges/hrx\$5/hr)	3K	
Overhead	<u>11K</u>	
Subtotal	\$ 271K	\$ 8.70
 <u>Tungsten Space Processing</u>		
Direct Material (estimate)	\$ 100K	
Direct Labor (estimate)	300K	
Shuttle Service Charges (6240x\$952)	5940K	
(See Separate breakdown)		
Overhead (estimate)	<u>300K</u>	
Subtotal	6640K	<u>212.82</u>
 Total Target Segment	 \$6911K	 \$221.52*

*This figure rounded to \$222 used for financial analysis of tungsten business, and based on 31,200 units output

Figure VI-4. Unit Manufacturing Cost - Tungsten Target Segments and Tungsten Targets

years of the 1982-1992 production period. The 31,200 target segment yield does not allow for shrinkages encountered later in target finishing, which reduces the final yield for 26,676 units.

VI.2.1 SHUTTLE/SPACELAB OPERATION COSTS AND RESOURCE COSTS

Space operations costs at an annual production level of 31,200 target segments (6240 charges) are estimated at \$6640K (Figure VI-4). Most of this amount (\$5940K) is for shuttle service charges, which are calculated in Figure VI-5.

VI.2.2 DEFINITION OF ADDITIONAL NON-SPACE PROGRAM COSTS

The raw tungsten preparation process step, which is the only ground process involved in producing tungsten target segments, accounts for only 4% of the unit manufacturing costs of a target segment (Figure VI-4). The target finishing step, which is not included in the space processing venture, would be performed by an x-ray tube manufacturer. The unit price for the target segment, as used in the financial assessment of the venture, is estimated as the price which an x-ray tube manufacturer could afford to pay for a segment and incorporate it into a high-performance, premium-priced x-ray tube. An assumption has been made that the x-ray tube manufacturer will be able to dispose of large quantities of high-ductility tungsten scrap as part of his target finishing process. Details of the analysis on which this segment price was based, are not included in this report for proprietary reasons, and do not affect the assessment of the space opportunity.

The facility for preparation of raw tungsten charges (probably in pre-shaped, pressed and sintered form) would be located in existing plant space of a target manufacturer or x-ray tube manufacturer, and no new plant would be required. Quality controls for the tungsten preparation process would hinge on the needed preciseness of starting tungsten characteristics, a factor to be investigated in the research and development program.

Basis: 6240 charges per year

	<u>Annual Charges</u>
Up-transport Volume	
Facility (once per yr) ($4.0\text{M}^3 \times \$13,760/\text{M}^3$)	\$ 55K
Cartridges ($10.4 \text{ cartridges} \times 0.2\text{M}^3 \times \$13,760/\text{M}^3$)	29K
Up-transport Weight	
Facility ($727\text{kg} \times \$110/\text{kg}$)	80K
Cartridges ($10.4 \text{ cartridges} \times 800\text{kg} \times \$110/\text{kg}$)	915K
On-orbit Energy	
($6240 \text{ charges} \times 10.6\text{KWH} \times \$40/\text{KWH}$)	2646K
On-orbit Crew	
($6240 \text{ charges} \times .0111 \text{ man hr/charges} \times \$6450/\text{hr}$)	447K
($10.4 \text{ cartridges} \times 2 \text{ man hrs} \times \$6450/\text{hr}$)	134K
On-orbit Data Transmission	None
On-orbit Data Processing	None
Down-transport Weight	
Facility (once per yr) ($727\text{kg} \times \$180/\text{kg}$)	131K
Cartridge ($10.4 \text{ cartridges} \times 800\text{kg} \times \$180/\text{kg}$)	1498K
Ground Operations (Volume related)	
($4\text{M}^3 \times \$1280/\text{M}^3$)	5K
Ground Operations (Complexity related)	<u>None</u>
Total Charges	\$5940K
Space Charge per Tungsten Charge (6240 charges)	\$ 952

Figure VI-5. Calculation of Tungsten Production Space Charges

VI.2.3 ANALYSIS OF TOTAL PRODUCTION COSTS

The selling price for tungsten target segments is limited by what x-ray tube manufacturers will pay. Thus, the potential for profitable space processing operations lies in the ability to achieve a low unit manufacturing cost. The high contribution of space service charges to unit cost (86%) demonstrates the importance of finding a favorable basis for space service charges to this business. The basis on which in-space energy charges were estimated is especially critical, since the \$40 per KWH rate used is based on a large, low-cost-per-KWH source which is presently undefined. Even at the optimistic energy cost per KWH used, this item accounts for about 38% of the target segment unit cost. The yield factor used in the space process throughput analysis is quite high (99%) based on recent laboratory results. If this yield factor cannot be achieved in production, it would have a direct effect on unit cost.

VI.3 ANALYSIS OF COST/VALUE

The tungsten target segment business venture presents a potential for profitability, but one which requires further examination before any conclusions are drawn. The inherent process characteristics (heavy space product of high energy consumption) suggest a vulnerability to space service charges that must be studied to confirm that an acceptable profit margin can be achieved.

VI.3.1 DERIVATION OF GROSS MARGIN

Gross margin, or the difference between unit manufacturing cost and selling price, for the baseline case (Case B) is estimated at $\$442 - \$222 = \$220$ per unit in 1992. This unit margin applies to all years of the forecast, since no basis was available for projecting other values. (See Cash Flow Analysis). Gross margin allows for net profit and expenses other than shop cost (i.e. R&D, engineering, selling, administration, depreciation, and interest expenses, and federal income taxes.) This margin gives a per cent net income to sales of 13 per cent in 1992 (Case B).

VI.3.2 IDENTIFICATION OF SIGNIFICANT COST/VALUE ASSUMPTIONS

The basic assumption in forecasting the business is that an x-ray tube containing the space-processed tungsten target will deliver 50% more operating hours, and thus can be premium priced at a level perhaps 130% of standard tube price. This condition, plus the ability of the tube/finished target manufacturer to dispose of tungsten scrap at a price on the order of \$100 per kilogram leads to the unit selling price of \$442. Success in achieving these points is assumed to lead to sales at a level which is 25% of the world demand for x-ray tube targets.

The baseline case (Case B) assumes that NASA will fund and conduct an R&D program sufficient to demonstrate process feasibility and that the user business will pay for subsequent conversion to a production capability.

A fundamental set of assumptions, of course, is that the required low DBTT tungsten can be made and bonded to a molybdenum substrate, and that the space environment is essential to this process.

The space service charges, a major element of unit cost, are based on the BUS Phase III model. Any changes in the basis for assigning space charges will have a significant effect on the forecasted business viability.

VI.3.3 SENSITIVITY ANALYSIS

The "present value" of the product venture (discounted at 10%) has been used as a common measure for assessing the sensitivity of the venture to the estimates used for the various cost elements. Each of the 15 parameters used in the cash flow analysis was varied $\pm 10\%$ and the financial forecast was calculated for each case, a total of 30 projections. The resultant present value in each case was then compared with the baseline case present value, giving the delta low (-10%) and delta high ($+10\%$) figures as shown in Figure VI-6. The parameters with the largest changes in present value are thus of most interest. The high impact parameters are plotted in Figure VI-7.

INVEST - INTERACTIVE NEW VENTURE EXAMINATION AND SENSITIVITY TEST

SENSITIVITY ANALYSIS OF CHANGE IN PRESENT VALUE FOR 10 PCT. CHANGE IN PARAMETER VALUE

ITEM	PARAMETER	DELTA LOW	DELTA HIGH
1	INTEREST RATE	65289.	-65289.
2	UNITS MANUFACTURED PCT.	1462137.	-1505459.
3	AVERAGE INVENTORY PCT.	43759.	-43759.
4	ENGINEERING EXPENSE PCT.	61669.	-61669.
5	SELLING EXPENSE PCT.	102318.	-102318.
6	ADMIN EXPENSE PCT.	123337.	-123337.
7	RECEIVABLES PCT.	72604.	-72604.
8	DEPRECIATION PERIOD(YRS)	5368.	-5617.
9	OTHER INVESTMENT PCT.	-18151.	18151.
10	TOTAL MARKET UNITS	-427452.	427452.
11	MARKET SHARE PCT.	-427452.	427452.
12	UNIT PRICE \$	-1950860.	1889589.
13	UNIT MFG'D COST \$	1462137.	-1505459.
14	R + D COST \$	179767.	-179767.
15	ANNUAL PLANT + EQUIP \$	81410.	-81410.

PRODUCT IS TUNGSTEN CASE B
BASELINE PRESENT VALUE = 1662752.

Figure VI-6. Tungsten Parameter Sensitivity

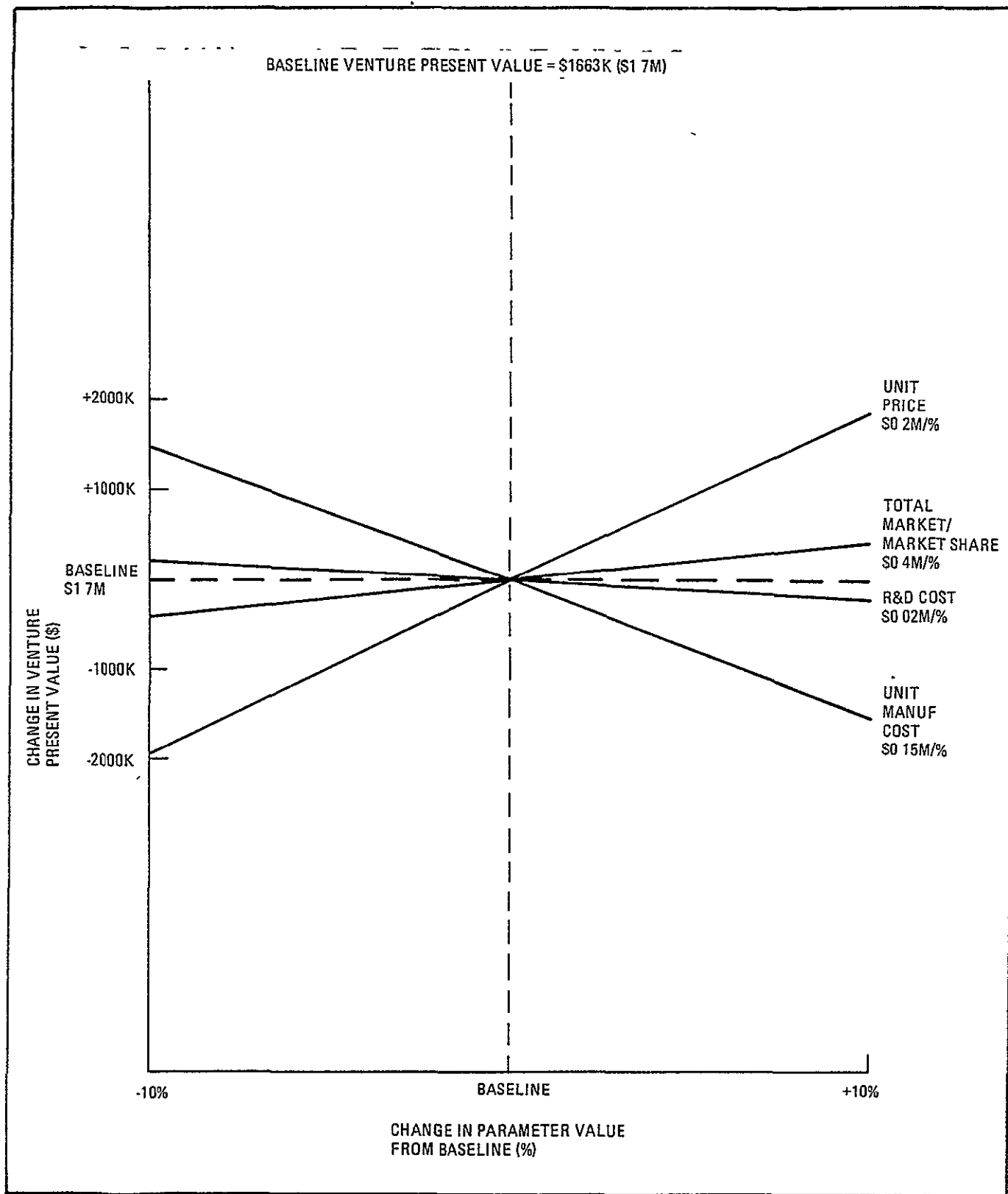


Figure VI-7. Tungsten Parameter Sensitivity

EWID
DATE
8-2-77



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Headquarters Valley Forge, Pennsylvania □ Daytona Beach, Fla. □ Cape Kennedy, Fla.
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